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New Foundations for Growth: The U.S. Innovation System Today and Tomorrow

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Preface

This document culminates a year-long process of soliciting input and examining options for government action to support the national innovation system. The project was conducted in FY2000 by the Science and Technology Policy Institute at RAND for the National Science and Technology Council (NSTC) under the direction of Dr. Duncan Moore of the White House Office of Science and Technology Policy. NSTC co-Chairs, Morton Downey (Department of Transportation) and Gary Bachula (Department of Commerce,) provided direction for the interagency committee. A steering committee with representatives from business groups (the Council on Competitiveness, the Industrial Research Institute,) state groups (the State Science and Technology Institute,) and academic groups (the Woodrow Wilson Institute) advised the effort.

The process included a call for papers that went out to hundreds of businesses, business organizations and associations, and laboratories to seek ideas for how to either remove obstacles to innovation or improve government policy in support of innovation. The goal was to identify those policies that did not require new government budget authority and which could be accomplished in the near-term (1-3 years.)

The initial set of papers, published on a web site established for the effort, were synthesized into a set of questions for the Summit on Innovation held at the George Washington University in December 1999. This was followed by a June 1999 workshop exploring various scenarios as they might affect the national innovation system under diverse conditions. A synthesis of the findings from all these efforts, as well as a review of relevant literature, resulted in the policy options contained in this document.

The project team received direct guidance from Lori Perine, Deputy Associate Director for Technology at the White House Office of Science and Technology Policy.

About the S&T Policy Institute

Originally created by Congress in 1991 as the Critical Technologies Institute and renamed in 1998, the *Science and Technology Policy Institute* is a federally funded research and development center sponsored by the National Science Foundation and managed by RAND. The Institute's mission is to help improve public policy by conducting objective, independent research and analysis on policy issues that involve science and technology. To this end, the Institute

- Supports the Office of Science and Technology Policy and other Executive Branch agencies, offices, and councils
- Helps science and technology decisionmakers understand the likely consequences of their decisions and choose among alternative policies
- Helps improve understanding in both the public and private sectors of the ways in which science and technology can better serve national objectives.

In carrying out its mission, the Institute consults broadly with representatives from private industry, institutions of higher education, and other nonprofit institutions.

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Summary

The National Innovation System

The transformation of the U.S. economy over the past twenty years has made it clear that innovations based on scientific and technological advances have become a major contributor to our national well being.[1] The system that supports this process has emerged as one of our most important national assets, as important a source for growth today and in the future as have been in the past the nation's natural resource endowment, the talents and dedication of its workforce, and the accumulated stock of its capital goods.

Our understanding of innovative activity in the U.S. has also changed and grown more sophisticated. Discussion of innovation has shifted from a focus on products (identifying critical technologies, for example) to processes, from individual outputs to the mechanisms for producing those outputs. During this transition, the realization has grown that this system constitutes a dense and complex network of interconnected parts. The major actors in this system–the private sector, government agencies and labs, universities, the non-profit research sector–relate to each other in complex ways neither easy to describe nor trace through the system.

This interconnected network constitutes what has come to be called a national innovation system. Given the fundamental importance of this system to public welfare and the continuing importance of government as both a participant and a provider of crucial elements of support, it is appropriate to understand what kinds of government actions (or for that matter, inactions) would contribute most to the continued development and health of the system or, conversely, detract from that development and health the least.

To address this set of issues, the National Science and Technology Council organized a series of events to weigh the insights and opinions of participants and observers from every part of the innovation system – businesses, industry groups, labor, federal and state government, and universities. This report is based on discussions begun with the latest National Critical Technologies Review, the study "New Forces at Work," and continued through the National Science and Technology Council's Summit

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[1] A longer executive summary of this document may be found in RAND MR-1338.0 {}

on Innovation and a culminating Innovation Scenarios Workshop held under the same auspices.[2]

The report seeks to emphasize issues and proposals that have received support across the political spectrum in an attempt to draw from the discussions a first step toward common ground on current and emerging needs. This task is a difficult one -- given the diversity of topics covered, the many interests involved, and the multiplicity of views expressed—and not without risk. While the authors have attempted to provide an accurate report of discussions, inevitably there is much room for interpretation. The reader should not, therefore, read what follows as the findings from detailed analysis but rather as an effort of reportage providing a framework for a series of wider discussions.

Strengths and Stresses in the National Innovation System

During the Innovation Summit, the participants were asked in the course of topical working sessions to consider a series of questions about the current state of the national innovation system:

- what seems to be working well?
- what refinements or reforms to existing policy institutions or programs may be needed?
- what new institutions or programs are needed?
- what new research or study is needed on the operation of the national innovation system? On effects of government policies and actions? And on new methodologies of assessment and decisionmaking?

In the course of these discussions, participants also suggested responses to the mirror image of these questions: What areas are not proper for public involvement? What programs or institutions have outlived their usefulness? The passages below attempt to capture the main themes that emerged from the discussion these questions prompted.

The Private Sector

U.S. business has shown a remarkable ability to innovate and to capitalize on innovation in the marketplace. The elements of the national innovation system largely centered in the private sector possess notable strengths, among them:

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[2] Held respectively on November 30 – December 1, 1999 at George Washington University and June 21-22 at RAND Washington. Please see Appendix for fuller description.

- Industry responds rapidly to new technologies and new ideas in the marketplace.
- Private firms are flexible and adaptive, certainly more so than the governmental or academic sectors, and can accommodate change more easily.
- The efficiency with which industry approaches the product life cycle is also a strength of the business sector.
- Entry, exit, and the factors involved in ramping up a new product or business or allowing unprofitable activities to wind down is a process facilitated well by industry.
- Capital flows easily and is less bounded than in other sectors, ensuring that promising new areas have funding.
- The overall mobility of factors, the willingness to move manufacturing or research to more productive locations, the willingness to license technology, and the ability to retrain workers, are all strengths within the system.

To point out the success of this machinery for developing and implementing innovation is not to suggest that the private sector can address all concerns equally well. We are speaking not necessarily of failures or shortcomings but rather of weaknesses that may inherently exist, often as a concomitant of successfully pursuing the course the private sector demands:

- Managing under uncertainty becomes increasingly challenging as competition widens and the pace of change increases.
- Balancing needs of customers with social welfare is not necessarily consistent with the fiduciary responsibilities of management.
- Relatedly, long-term systemic consequences of individual actions are beyond the power of firms to foresee or to counteract.
- The "down side" of the private sector's skill at marshaling resources for investment in “hot” areas is that other opportunities that may have longer term or less appropriable pay-offs get insufficient attention.
- And, of course, externalities and market failures of various sorts are by definition beyond the purview of private enterprise.

The Public Sector

Many of the holes left by the private sector in the fabric of innovative activity are not owing to failure of action or short-sightedness. Rather, they require perspectives and actions that are not rightly viewed as the responsibility of firms. There is an economic argument for the public sector to play an appropriate part. The resulting roles

include direct and indirect assistance to the processes of innovation, as well as support for the infrastructure that enables economic activity.

Direct support actions include:

- Funding for basic research and development ;
- Protecting intellectual property, copyrights, and trademarks and the legal system of judges and courts that help defend these rights;
- Aiding efforts to set technical standards;
- Agricultural and manufacturing extension services, particularly those helping small business;
- Procurement decisions by agencies;
- General programs lending more tailored assistance through programs like the Small Business Innovation Research program or the Advanced Technology Program.

More indirect efforts include:

- Protecting the integrity of the overall financial infrastructure;
- Fiscal policies such as taxation and the granting of tax credits;
- Improving the educational system;
- Developing transportation and information infrastructures that facilitate commerce;
- Assisting trade through export financing, protection against unfair trading practices by other countries, identification of trading opportunities, and efforts to open markets.

Government has had a substantial effect on the success of the national innovation system by operating through these mechanisms. Changes in policy have led to noticeable changes in the system's operations, often in response to private sector requests. In addition, public sector institutions have the ability to articulate a public agenda and then act as catalyst. Government's role as a convenor of different interests helps to build bridges across disciplines and between upstream and downstream

activities. One of the key features of the innovative process is network building. It is through close interaction with competitors, suppliers, and customers that dynamic markets are created. Relationships among institutions are becoming an important policy issue for government agencies. When such networks are weak, public institutions may be used to put in place a process enhancing the connections between firms and the other organizations that contribute to the innovative process.

Government is able to mobilize capital in directions that are difficult or of little interest to industry. By focusing on areas that need particular help, or where basic research is not being conducted, government is able to leverage investment and create new knowledge that industry can use. Such funding of basic research and infrastructure allows private industry in turn to also gain leverage (e.g., through membership in the NSF's Engineering Research Centers.) Government is also a large and influential purchaser of goods and thus has influence on how products are developed, used, and marketed.

Finally, government enforces rules that help to keep the system healthy. Moreover, it is left to public sector institutions to provide ways and means for dealing with issues arising from private sector actions that are not adequately addressed by markets, such as environmental clean-up or consumer protection. When viewed as part of the larger system within which innovation takes places, these rule-setting roles and efforts to ensure consumer safety are key to the overall facility with which innovation takes place.

Policy Options in Support of a Healthy National Innovation System

Several areas were identified by participants as being appropriate and useful for early policy attention by any U.S. administration. In what follows, the intent is not to lay out a narrow policy course to be followed by individual government agencies or other public policy institutions. Rather, we emphasize increasing the generality of the discussion of policy directions. Individual agencies or policymakers may then use these policy directions to craft more specific actions or decisions. The options we are not meant to be mutually exclusive. Rather, they are arranged to suggest means for **ensuring inputs** to the system, **maintaining the environment** for private and public innovative activity – and improving it, **supporting communications** between elements of the system, and finally, **better understanding the dynamics** which drive the national innovation system and creating appropriate policy in support of them.

A. Ensuring Adequate Inputs

1. Education and training

Options: a) Improve the quality of K-12 education in general and raise the level of math and science education in particular.

b) Expand options for access to science and technology education among groups currently under-represented in the workforce of those fields.

c) Increase opportunities for re-training in science and technology for the current work force.

d) Take measures to determine that resources and incentives are in place to ensure the output of a sufficient supply of technically trained professionals from institutions of higher education.

2. **Portfolio of Public Research**

Options: a) Ensure adequate levels of public funding for fundamental science and engineering research.

b) Funding decisions should be made in a more informed process for assessing priorities and providing balance across fields in a manner commensurate with the complexity of the national innovation system.

3. **General Policy to Enhance Resources**

Options: a) Consider whether making the R&E tax credit permanent would provide sufficient and necessary general incentive to the national innovation system and the larger economy.

b) Evaluate the effect of the R&E tax credit with a view toward determining where within the national innovation system there is most influence, what changes should be made to existing regulations and where other instruments might be required to achieve the desired effect.

4. **Targeted Policies to Enhance Resources**

Options: a) Evaluate the development of mechanisms to encourage investment in emerging technology sectors that currently receive limited venture capital funding and how such sectors and points of advantageous entry might be determined.

B. Maintaining a Favorable Environment

1. **Intellectual Property Protection**

Options: a) Consider what measures may be required to ensure that patent review processes maintain currency with new technology developments.

b) Assess the effects of policy changes (such as the Bayh-Dole and Stevenson-Wydler Acts) on the flows and balance of government-funded research and their effects on private sector activities.

2. **Standards**

Options: a) Begin a systematic review of the process for setting technical standards considering both the potential importance and limitations of government involvement.

b) Consider the role and process of standard setting as an aspect of U.S. trade policy.

3. **Infrastructure**

Options: a) Assess national needs for new measurement and testing systems that would create a benefit across industries.

b) Examine federal investment priorities to ensure public investments in infratechnologies are sufficient to sustain the growth and development of the national innovation system in desired directions.

4. **Partnerships**

Options: a) Evaluate the importance of various kinds of partnerships, as well as public-private consortia, in pursuit of innovative activity, determine when the public good would best be served by their coming into being, and consider how these may be fostered.

b) Define clearly where the boundaries for legal cooperation and research lie among firms in the private sector as well as between firms and the government.

c) Consider what policy guidelines would be needed for informing the construction and operation of partnerships with a public component.

C. Improving Communications

1. **Coordination within the Public Sector**

Options: a) Raise the awareness of federal agencies to issues affecting the national innovation system and their own roles within that system.

b) Seek to define and identify best practice with respect to R&D priority setting, project selection, and technology transfer across federal agencies and promote learning and transfer of such practices to other settings.

c) Seek opportunities to create or use existing forums and venues to foster discussion among federal agencies, between federal agencies and their state and local counterparts, and between government, industry, and academia on issues of common interest affecting the national innovation system.

2. **Industry and Government**

Options: a) Seek ways to recognize explicitly the de facto partnership and mutuality of interest between public and private sector institutions in support of the national innovation system and to enhance the complementarity of activities.

3. **Improving Understanding by the General Public**

Options: a) Raise public awareness of the importance of innovative activity and what is required through public actions to support that activity.

b) Raise the prominence of formal awards for leadership in the field of technology development.

D. Maintaining Dynamism

1. **Toward Better Understanding of the National Innovation System**

Options: a) Improve timely access to available government agency data on innovative activity; harmonize existing government data bases.

b) Increase incentives for agencies to collect data on innovation and technology use and transfer through special surveys and by expanding routine collections.

c) Develop new measures and data categories to improve understanding of the innovation system and the interplay between public and private actions.

2. **Anticipating Needs and Consequences:**

Options: a) Explore new methods and means to assist in formulating policies that will be adaptive and robust to a variety of possible outcomes rather than static and restrictive.

b) Explore new methods and means to enhance foresight and forward thinking about developments in the national innovation system and the implications of its actions for the society and economy.

3. **Measuring Performance in R&D**

Options: a) Work to improve methods for measuring the long-term social and economic performance of investments in basic research.

4. **International Dimensions**

Options: a) Identify centers of excellence in science and technology to encourage linkages and leverage across national boundaries;

b) Examine the global patenting system for ways to improve process efficiencies;

c) Identify ways that government can facilitate product and process standardization across national boundaries and determine when it might be appropriate to do so from the perspective of U.S. interests.

Policy Options for Near-Term Attention

Given the complex and interactive nature of the national innovation system, no single policy action will serve as a sole means for enhancement. However, in the course of preparing the policy directions outlined above, the project team came to believe that

they were not all necessarily of equivalent weight and immediacy. Some may be seen as candidate early agenda items for careful consideration by any federal administration seeking to support innovation. These options fall into three categories: 1) those reflecting a change in federal government policy and needing budgetary action; 2) those requiring legislative action; and 3) those needing near-term and effective examination and study.

Budgetary Action

- Among the options listed in the previous section, perhaps the most important is **ensuring an element of stability and adequate levels of public funding for fundamental science and engineering** (A.2.a.). Money should not simply be thrown at the R&D system in the expectation that useful outputs will ensue. Increased funding across a carefully constructed "portfolio" of investments will help ensure the health of the national innovation system.

Legislative Action

- Corresponding to options related for publicly funded R&D, a parallel item that should command early attention is to **carefully consider the benefits and implications of making permanent the R&E tax credit** (A.3.a.)
- To make certain that current arrangements for assigning intellectual property from publicly funded research efforts fully serve the public purpose, **assess the effects of policies put in place by legislative changes such as the Bayh-Dole and Stevenson-Wydler Acts on the flows and balance of government-funded research and their effects on private sector activities and consider whether updating the legislation may be necessary**. (B.1.b.)

Preparatory Action

- In the crucial realm of intellectual property rights and their protection, the administration should **carefully consider the global patenting system** (D.4.b.) and the effects of varying protocols and regulations on the ability of the U.S. to promote its products in world markets. Relatedly, an improved understanding of the flow and balance of **government–funded research and the effect of technology transfer on the private sector** (B.1.b.) is crucial for a clearer policy perspective on the overall system.
- Increased attention should be paid to **opportunities for training and re-training the science and technology workforce** (A.1.c.)

Finally, although broad in concept, **raising awareness within federal agencies of their role in providing the infrastructure for the national innovation system** (C.1.a.) could play an important role in the consideration of policy, improving its formulation, and better serving the public interest.

Acknowledgments

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I. Introduction: The Growing Role of the Nation's Innovation system

This document derives from an extended National Science and Technology Council (NSTC)–sponsored discussion on the character and state of health of the national innovation system of the U.S. This section describes the NSTC process and also elaborates on the concept of a national innovation system, an informal network composed of many elements at several levels. The authors suggest that this system might best be viewed as belonging to the category of "complex adaptive systems." This observation has important implications for policy and the discussion elaborates on the practical meaning of the term. Finally, we discuss the role for public policy within the context of this ever-changing, dynamic national innovation system.

Purpose

The startling transformation of the U.S. economy over the past twenty years has made it clear that innovations based upon scientific and technological advances have become a major contributor to our national well-being. Even more than the weight of individual innovations, we have witnessed the coming into being of a continuous process of change which has itself become the new status quo. The system that supports this process has emerged as one of our most important national assets – as important a source for growth today and in the future as have been in the past the nation's natural resource endowment, the talents and dedication of its workforce, and the accumulated stock of its capital goods.

The present document was written to offer a structure for considering the effect of public policy actions (or inactions) on the U.S. national innovation system. Largely based on discussions begun with the latest National Critical Technologies Review, the

study "New Forces at Work",[3] and continued through the National Science and Technology Council's Summit on Innovation and a culminating Innovation Scenarios Workshop held under the same auspices,[4] the paper attempts to distill a central position from among the broad spectrum of opinion on the nature and state of health of the national innovation system. It then suggests policy guidelines and proposals for maintaining that system. In this case, maintenance includes not only the amelioration of present problems, but also an ability to anticipate those likely to appear in the future and, what is more, to ensure an ability to take full advantage of opportunities presented to us.

The emphasis of this paper is intentionally placed on issues and proposals that have received wide support across the traditional political spectrum on current and emerging needs. The purpose of this document, therefore, is to draw from the NSTC-sponsored discussions a first step toward common ground. This task is a difficult one -- given the diversity of topics covered, the many interests involved, and the multiplicity of views expressed—and not without risk. Therefore, rather than issue a rigorous set of specific policy initiatives, this report seeks to provide broader guidelines to policy by illuminating areas of need and showcasing suggestions that have emerged from a number of quarters.

We develop a case below for viewing the national innovation system as a "complex adaptive system". This perspective implies a reticence in making hard and fast policy recommendations and requires of policymakers more recognition of the need for crafting policy to suit the dynamic nature of the system it is intended to address. Fully recognizing that so much of what occurs in the national innovation system results from the actions of individuals and private sector institutions, we also make a case for believing that carefully crafted action by public sector bodies may complement, enhance, and support the benefits ensuing from private initiative and activity.

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[3] Please see Appendix for fuller description.

[4] Held respectively on November 30 – December 1, 1999 at George Washington University and June 21-22 at RAND Washington. Please see Appendix for fuller description.

In collating, assessing, and distilling the wide range of views, analyses, and statements made in the various venues this paper seeks to summarize, there is much room for interpretation. While the authors have attempted to provide an accurate report of discussions, the reader should not read what follows as the findings from detailed analysis but rather as an effort of reportage providing a framework for a series of wider discussions. Inevitably there is much room for interpretation.[5] As a further guide to reader understanding, the authors of this document speak most strongly in their own voice in this first chapter, less so in Chapter II, "The Nation's Innovation System Today – And in the Future", and have worked hard in Chapter III, "Policy Directions in Support of a Healthy National Innovation System", to stay as close as possible to the discourse at the various summits and workshops. The final chapter, "Options for Near Term Attention", like the first, once again presents a synthesis based on the authors' understanding. Its policy options, like those in the rest of the document, are offered in the spirit of providing a basis for further conversations rather than definitive prescription. In no case has the present discussion been pressed beyond the tenor of those held at the NSTC-sponsored events.

What Is the National Innovation System?

There has been an increased sophistication in the discussion of innovative activity in the U.S. since the time the topic first seriously entered public policy discourse in the 1980s. Before then, of course, there was scholarship and policy in this realm but only at that time did the issue take on a sense of national urgency bound up with a decline perceived by some in the relative standing of the U.S. as a competitor in international trade.[6] Then, the focus was on discrete "critical" technologies as inputs to

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[5] The authors have attempted to provide as objective a synthesis as possible, but in the final analysis any work of this type must to an unavoidable degree also be a product of the world view its authors possess. Therefore, while every attempt has been made to place the present discussion on an objective footing, the views expressed must be understood to represent those of its authors and not in any way necessarily those of the Office of Science and Technology Policy, the National Science Foundation, the National Science and Technology Council, or any other public or private institution.

[6] There was a similar period in the late 1950s when the need to rise to the apparent challenge of the Soviet launch of Sputnik was a commonplace of public discussion. There are similarities in the sense of perceived threat but also differences in the reality and nature of the challenge as well as in the complexity of possible solutions. While the earlier period saw more discussion of S&T policy issues, concern and attention waned somewhat in the ensuing two decades.

production. These technologies were implicitly viewed as a set of discrete, well-defined, and self-contained objects.[7] The question, simply put, was whether the U.S. decline in relative standing as a trading partner stemmed from an absolute decline in the ability of the nation to marshal and apply crucial technologies effectively. This sense of slow crisis led, among other things, to the requirement for the Administration to produce a biennial report to Congress on the state of critical technologies in the U.S.[8]

By the time the last report in the limited series was issued in 1998, it became clear that policy attention was beginning to change its focus, partly, to be sure, because of having met the challenge successfully, but also owing to a more deeply developed understanding of the role technology plays in our national life – an understanding sooner and more widely arrived at in business than in government. This transition received corroboration from the tenor of discussion during the two NSTC follow-on activities mentioned above. The conversation was less about individual technologies or even technology per se than about coming to an accurate reading of the nature and state of health of the "national innovation system" which produces it.[9]

A National Innovation System

The focus of those concerned with technology policy has been shifting from product to process, from individual outputs to the machinery for producing those outputs. Awareness of the existence of this national innovation system, and an increased willingness to name it as such, has grown during the course of this transition. It constitutes a dense network of interconnected public and private sector actors and institutions.

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[7] For a history of the critical technologies concept, see "What is a *Critical* Technology?", Bruce Bimber and Steven W. Popper, RAND DRU-605-CTI, 1994.

[8] {refs to NCTR I-IV}

[9] The term dates at least from the early 1990s. See, for example, *National Innovation Systems: A Comparative Analysis*, ed. Richard R Nelson, Oxford U Press, New York, 1993.

At root, the national innovation system carries on the closely related functions of producing and applying new knowledge, principally of a technical nature.[10] It contains within it many elements connected in a dense network of interactions, signals, feedbacks, and flows of ideas, information, resources, goods and services. One way to describe the system is to name those elements. At the most coarse-grained level, we might divide these elements into the spheres of knowledge production and knowledge utilization.[11] Within the first sphere we immediately think of scientists and engineers working sometimes on their own but most often in laboratories or R&D facilities operated by private industry, by universities, and to some extent by the government. Yet, much innovative activity occurs outside the formal precincts of R&D labs. R&D departments tend to be an artifact of large firm organization. But in all company settings much "fixing" that amounts to innovation is done on the line by employees not principally charged with the innovation task. This type of informal activity too is an element of the national innovation system.

This last comment makes clear that the distinction between the production of knowledge and its utilization is one of many characterizations we make to suit our analytical purpose in describing this system -- but which may have little to do with any boundary that exists in real practice. These fine lines of separation we construct to permit description tend to break down when we examine actual innovative activity. Among the principal utilizers of knowledge produced by the national innovation system, for example, are the producers themselves who utilize output from other knowledge producers. They are joined as utilizers of knowledge in pursuit and adoption of innovation by a host of others: new and existing firms across all industrial sectors, entrepreneurs, government agencies, venture capitalists, and so forth.

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[10] To understand the national innovation system in its fullest capacity, it is best to construe what is meant by technology quite broadly. Technology consists of "activities, directed to the satisfaction of human needs, which produce alteration in the material world [and the cumulative result of such activities."] Note that the emphasis is on the activities and not the physical means supporting them. In this sense, new forms of organization, for example, qualify as technological innovations. (Quotation from V. Gordon Childe, *The Oxford History of Technology* (vol.I, p. 38))

[11] This taxonomy draws on a characterization of the national innovation system presented by Gary Bachula, formerly of the Department of Commerce, at the NSTC Innovation Summit, 30 November 1999.

What becomes clear is that a description limited only to the "nouns" within the national innovation system misses its most interesting and important aspects. The participating individuals and institutions are only that system's most visible feature. It is the connectivity and flow among these nodes that make this a network, a system rather than a collection of parts. These flows take the form of real resources, financial exchanges, formal statements, formal and informal transmission of knowledge and ideas through various vehicles, and ultimately different embodiments of technical knowledge into actual products or services. The flows themselves are required to conform to a wide range of institutions, regulations, and norms for interaction. And this network and its flows are both complex and to all appearances both "untidy" and disorganized. Yet it appears to be quite effective if not efficient in the most narrow sense of the word.

The national innovation system in the U.S., and to a varying degree in much of the developed industrial world, is characterized by having many of its most important activities carried forward by private-sector entities operating under the influence of the market. This means the national innovation system in its most basic form may be said to operate through the interactions between two sets of institutional elements. On the one hand is a feature both familiar and remarkable: progress occurs through the actions of a multitude of independent potential technology providers who compete vigorously with each other. The traditionally strong relative anti-trust policy stance by the federal government makes this an even more salient factor in the U.S. than in other developed industrial economies. The other set of institutional elements combine into the range of forces we refer to as "the market." Acting as mid-wife, the market and the glittering prizes it offers prompt the entry of new firms and enhance the willingness of existing firms to explore new avenues. On the far end of the process, in most cases of technological advance, market forces act as the judge rendering the final verdict on the innovations that will receive wider dissemination and even on which firms are to survive.[12]

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[12] This, of course, presents an idealized portrait of the system, but one that holds true in most instances. Influence from non-market forces and innovation by organizations other than private concerns does occur, occasionally with profound result, but the instances are usually exceptional.

A Complex and Adaptive *National Innovation System*

What arises through this evolutionary process, almost biological in its essence, is a national innovation system that when viewed as a totality is complex, dynamic, and adaptive. As such, it displays the phenomena associated with the family of complex adaptive systems:

- The national innovation system is comprised of many agents of various types, operating according to a wide range of incentives, goals, rules of thumb, and other decision making systems.
- The system is characterized by the self-organization of its own structure. Rather than being crafted according to any previously planned design, the network of institutions and linkages has arisen through myriad actions taken by the system's constituent agents operating according to the rules suggested above.
- It is a system of many feedback loops and signals. The directionality of its flows are more varied than the single direction implicitly suggested by the simplistically chronological rendering of its constituent activities as basic research, followed by applied research, and then development, innovation, adoption and ultimately diffusion.
- It is a system whose outcomes are almost impossible to predict over any meaningful time course. This befits an endeavor whose principal purpose is to delve into the unknown and which, the history of technology constantly reminds us, may take surprising turns on the road to determining what the proper application of the new knowledge it generates might be.[13]
- Finally, it is a system that does not operate according to a regime of strict proportionality and constant returns to scale – relatively small innovations and developments of new technology may lead to results almost beyond the scale of our imagining, as we have witnessed only in the last decade with the advent of the

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[13] The technical term for this type of phenomenon is "path dependence". That is, the ultimate outcome will be determined in large part by which of several alternative possible paths we take, themselves difficult to assay before hand. Consider, for example, the early history of the automobile when it was not clear until several decades into its development that internal combustion would dominate both steam and electricity as a means for propulsion.

internet and the World Wide Web. Relatively small investments in knowledge creation may lead to large dividends in more familiar form such as enhanced productivity, more sustainable economic activity, and richer, healthier, and more fulfilling lives.

These properties of complex adaptive systems generally, and of the national innovation system in particular, create a considerable challenge for policy analysis and formulation. Our present state of learning does not leave us as well-suited to understand this class of phenomena as we might wish. These characteristics explain why naïve approaches, usually prefaced by "if we can put a man on the moon, surely we can…" often lead to frustration.[14] If nothing else, the principle that government policymakers ought to make certain their tread in this area of policy is light and soundly grounded presents itself as a major lesson to be drawn from this insight. Given that the balance of innovative effort lies in the private sector, government interactions will most often be indirect.[15] Further, given that the system as a whole thrives on the rivalrous competition surrounding the development of useful knowledge and the implementation of technology, many questions will and ought to be asked about government actions in this arena. Policymakers in government must consider what actions on their part are enough and what too little; what is to be done and for whom is it to be done. And most critically, what is and ought to be the government role in the national innovation system.

The Role for Public Policy

The economic history of the U.S. shows an ongoing dynamic tension between the willingness, on the one hand, to put in place measures leading to the creation of "a more perfect union," and on the other a recognition that the nation's creative force may

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[14] In terms of systems analysis, the problem of putting a man on the moon is "simple" in that the larger problem can be decomposed into a series of smaller ones. The solutions to these constituent problems may then be recombined with the result that a lunar lander may be placed with safety on its intended target. Keeping disadvantaged 16-year olds in school, on the other hand, is complex in that a similar approach will often lead to surprising and unexpected outcomes, often precisely the opposite of what was intended.

[15] That is, the number of direct government efforts at technological innovation is relatively small compared to those conducted in the private sector. Government actions tend to be directed towards affecting this private sector effort through tax policies, procurement, education, infrastructure building and so forth.

only be fully unleashed in an environment that will support and encourage myriad private actions and initiatives. The genius of the U.S. system, from the framing of its Constitution onward, has been to reconcile this apparent opposition and harness both its elements into a workable structure, transforming apparent paradox into a uniquely fruitful productive force.

The innovation system operating in the U.S. today may truly be called one of the principal drivers of the contemporary world. It exists as a series of finely struck balances between individual initiatives and public needs. It was wrought principally through the motive force of the U.S. free enterprise system, a system predicated on government not overstepping its bounds of authority and expertise but also requiring from government effective fulfillment of its responsibilities.

We are entering a world where not only discrete changes in emerging areas of technology but the very dynamic of a continuous and accelerated process of change on all fronts will affect the way people think and behave in the world. This will be true for the private life of the individual and the public life of the nation, thus exerting a powerful force on traditional structures and modes of governance. Key emerging technologies will, in themselves, present unprecedented challenges for governments to address as will, in the aggregate, the very fact of a constantly changing technological basis for all of our society's interactions. Given this shifting background, what are the responsibilities of government and public policy in a rapidly transforming world?

The answer to this question is, both surprisingly and not too surprisingly, to continue attending to the basic functions of governance under the U.S. system. In broad measure, the legitimate purview for government operations outside the realm of national security lies in three areas: allocating public funds to public purposes and then responsibly managing their expenditure; monitoring and regulating private activity in the interest of a commonly perceived public benefit; and either setting national agendas or providing the occasion for agenda-setting activities to occur.

How do these basic functions of governance apply to the needs of and requirements placed upon the national innovation system? In exercising these functions, policies and actions ranging from drafting tax codes to environmental

mandates, from procurement practices to individual decisions over funding of R&D have played an important part in building the present fabric of innovation-related investment and activity. But looking at a higher level -- at the broad expanse of government influence and potential influence in this area -- two main lines of public stewardship emerge.

The first derives from the broad agreement in the U.S. that the healthy operation of the national innovation system depends upon an environment that will support private individuals and organizations in the pursuit of their own endeavors. Rather than usurp a role in this process, it is the responsibility of public authorities to ensure the vitality of this activity. To do this job properly will, in several circumstances, require positive action by government.

Beyond this, there is also a broad recognition that legitimate matters of public policy do exist that cannot and will not be addressed by the private sector. This last point came out strongly in the interviews with senior firm managers that constituted the bulk of the content of the last National Critical Technologies Review. There are important public concerns that are neither the duty nor within the competence of private interests to address.

It is in these two senses – a need to ensure a suitable infrastructure for the support of private activity and a constitutionally-mandated responsibility to tend to the public business – that a role for government emerges in consideration of the national innovation system. This reading of the proper role for government in the U.S. differs in conception from that which may be found in many other leading industrial nations. The government role is most certainly not to lead or direct; neither is it to be needlessly subservient nor ineffectually reactive. Rather, the government purpose in the U.S. conception of the national innovation system is twice-over that of a servant. In accord with the first aspect of public stewardship, it serves by maintaining a suitable environment for creation of demand, generation of supply, and establishment of an infrastructure that will support the needs of private effort. In the second instance of stewardship it ensures that public interests are articulated and met.

Yet, government is not a monolith in this area of policy, even at the federal level. In fact, if we consider only one activity, federal funding of basic research in science and engineering, we see just how remarkable this area of federal activity truly is. One is hard pressed to name other vital federal government functions in the discretionary part of the budget that cross so many Executive agency and Congressional committee lines as does the federal research enterprise. It is hard to think of any parallel federal activity that has such importance and such a broad involvement of so many agencies. There do exist specific programs spread about the federal structure (providing, for example, public assistance, income support, or transfer payments of various types,) but those are for the most part mandatory. Other vital government functions are contained in single agencies. And if this were not enough, the R&D planning problem needs not only to be funded, managed, and administered across the government, it needs to be applied across quite disparate fields of science.

The Nature of this Report

The discussion above was intended to highlight several key points:

- There exists an informal network of many individuals and organizations, the national innovation system, constituting the principal vehicle for developing and applying new technologies that in turn are an increasingly important factor in determining the nation's overall well-being.
- The national innovation system exhibits the characteristics of a complex adaptive system including, among others, self-organization, important yet hard- to-identify feedback loops, and an ability to frustrate most attempts at predicting outcomes.
- While the private sector is the driving force for most of the key activities of the national innovation system, these activities depend upon an environment greatly affected by government actions – and inactions. Further, there are legitimate public concerns in this realm that must be articulated and protected by public institutions.
- The challenges to governance in the areas of technology development and innovative activity are uniquely demanding because of the very ubiquity of the effect of these forces on so many public and private interests.

This series of insights provides the key to this document. It is not desirable to set forth a series of specific policy strictures as if there were either a single unified federal structure or a static, well-defined national innovation system operating according to established rules. Neither exists, so management in the strict sense is not a reasonable goal. Rather, a consideration of policy in the S&T area must recognize the appropriately limited purview of government authority and its multi-agency – and multi-level -- mechanisms for action. This document seeks to lay out a design for policy beneficial to the development of the national innovation system taking into full account the importance of the national innovation system in our national life on the one hand, and on the other the complexity of this system's relationship and interaction with government – and with many different levels and branches of government.

The premise is that there is value in laying out for explicit consideration a first draft delineation of areas of agreement on such a design. The document and its policy design may be referred to by mission agencies as they seek to fulfill their function, by various policy bodies in determining how actions in one area may have indirect effects on components of the national innovation system, and in the harmonization of activity by different levels of government. The intent is not to create a program for formally coordinated action or foreclosure of experimentation among agencies within the federal structure or between the federal and the state and local levels. This is no master plan for enhanced government control, management, or direction of the host of activities comprising the national innovation system. Rather, the purpose is to provide guidelines for thinking about how government can manage to do the people's business better.

II. The Nation's Innovation System Today – and in the Future

This section first makes the case for considering the national innovation system to be an increasingly important determinant of the course of affairs in the U.S. It then examines in some detail the sources of strength contributed to innovative activity by both the private and public sectors as well as where each sector's efforts need augmentation. Finally, this section will take a brief glance at dynamic forces that could serve to alter our perceptions of innovation, the innovation system, or the demands we place upon and the output we would seek from that system. All of these discussions are presented to motivate the filtering process that was used to determine the issues and directions for policy affecting the national innovation system that are the heart of this report and will be presented in the following section.

The Role of the Innovation System in the Nation's Life

In the past ten years we have witnessed two salient phenomena in our national life. The first of these has been the wave of fundamental changes in the world of business and the role played by research and innovation in supporting, forcing, and bringing about that change. We are experiencing structural shifts in our economy brought about by many factors but often attributed to the pace of technological change. The acceleration of that pace appears to be real:

- The number of science and technology alliances among businesses grew at more than 10 percent per year over the past 20 years.
- High-technology trade has grown to nearly 20 percent of manufacturing imports and exports, up from 10 percent in 1980.

And there are few in our society who have not been touched by the speed and bandwidth of information technology growing at exponential rates. There would also appear to be more of an entrepreneurial culture within firms than was the case in

previous decades. As we have seen, with these shifts and changes many of our assumptions and time-honored notions of how business operates and what should be the appropriate government role are inadequate in themselves to help us make good decisions.

The second salient phenomenon has been the extraordinary strength of the U.S. economy during most of the decade of the 1990s.

- Labor productivity growth has doubled during the mid-to-late 1990s.
- The overall unemployment rate is the lowest in 30 years, and the corresponding rates for minorities have fallen to record lows.
- The U.S. economy appears to be in a position to supply faster medium-term growth in living standards to households than has been achieved at any time since the 1960s.

Many voices connect these two phenomena – salient growth in the technological basis of the economy with the astonishing performance of that economy. The President's Council of Advisors on Science and Technology publicly cited the importance of R&D in this process: "The President's Council of Economic Advisors and other economists have pointed out the high rates of return on investments in research and development." In spring 2000, Federal Reserve Chairman Alan Greenspan repeatedly cited an unexpected leap in technology as being primarily responsible for the nation's record-breaking economic performance. In particular, a technology-based surge in productivity appears to be contributing substantially to our economic success.

Yet, straight-line extrapolation from current trends into the future would be folly. Globalization is leveling the playing field, changing the rules of international competitiveness, and collapsing the margins of technological leadership. Business groups have expressed concern that the U.S. is not preparing adequately for success in a world in which many more countries will acquire a capacity to innovate and government support for the process must be flexible and adaptable. The roles of government and industry are being challenged and need to be examined in the face of change. It behooves us to look at the strengths and stresses appearing within the

national innovation system for directions on what areas and issues might require attention. To do so, we may consider the respective spheres of industry and government in their relation to innovative activity in the U.S. in each sector

Current Sources of Strength and Stress

The Private Sector

It is the business of people in business to know what works. In this respect, companies have come to appreciate the value of the ability to innovate, to generate novelty, and to quickly adapt to and adopt changes that appear elsewhere. This is the source of new products, processes, and services as well as the means for protecting and extending those that already exist. The system of U.S. business has shown a remarkable, and dramatically improved, ability to innovate and to capitalize on such innovation in the marketplace. These elements of the national innovation system largely centered in the private sector possess notable strengths, among them:

- The rapidity of reaction time, the pace at which industry is able to respond to new technologies and introduce new ideas into the marketplace. When the end goal is clear, the movement from research to product development moves rapidly.
- Private firms are flexible and adaptive, certainly more so than the governmental or academic sectors, and can accommodate more easily to change. Firms have demonstrated a capacity to absorb changes in technology, even when they affect the entire enterprise.
- The efficiency with which industry approaches the product life cycle is also a strength of the business sector. Inefficiencies are often squeezed out of the production system as industry responds to the marketplace and, in a complex economy, this ability to improve efficiency and adapt quickly is critical to success.
- Entry, exit, and the factors involved in ramping up a new product or business or allowing unprofitable activities to wind down is a process facilitated well by industry. New markets and new applications for technology are principal driving forces in the private sector.

- Capital flows easily and is less bounded than in other sectors to ensure that promising new areas have funding. Private sector managers are accountable in the short term and therefore look to put capital where it will be productive, whether that be across national, disciplinary, or corporate boundaries.
- The overall mobility of factors, in addition to capital, the willingness to move manufacturing or research to more productive locations, the willingness to license technology, the ability to retrain workers, are all strengths within the system.

The dazzling success of this machinery for innovating and implementing innovation should not blind us to those areas where attention is required. We are speaking not necessarily of ills that should be viewed as failures or shortcomings but rather of assessing where weaknesses may inherently exist, often as a concomitant of successfully pursuing the course the private sector demands:

- Managing under uncertainty becomes increasingly challenging as competition widens and the pace of change increases. Efforts to assess where the company is going and how the market is changing are often foregone in favor of continuing to focus on the product or process.
- Balancing needs of customers with the needs of larger society is not necessarily consistent with the fiduciary responsibilities of management, although firms have become aware that the consequences of not doing so can become a significant impediment or even a major deterrent to future innovation when products fail or pollute. Nevertheless, the market remains an efficient engine for allocating resources, not necessarily for making higher level choices.
- Relatedly, long-term systemic consequences of individual actions are beyond the power of firms to foresee or to counteract.
- The mirror image of the private sector being able quickly to marshal resources for investment in "hot" areas is that other opportunities that may have longer term or less appropriable pay-off are overlooked or receive insufficient early-stage support.

The Public Sector

It is useful to elaborate the strengths and weaknesses of the private sector in supporting the national innovation system because it provides the backdrop against which to compare and contract the public role. The public sector has traditionally been expected to provide public goods that are not produced by industry. The resulting roles often include direct and indirect assistance to the processes of innovation, as well as support for the infrastructure that enables economic activity. These roles continue to be an important part of the fabric of innovative activity within the U.S. economy.

Direct support actions have included:

- Funding for research and development of a character not likely to be shouldered by private-sector institutions;
- General programs lending more tailored assistance through programs like the Small Business Innovation Research (SBIR) program;
- Manufacturing extension services, particularly those helping small business;
- Aid to product and process standardization;
- Provision of protections for intellectual property, copyrights, and trademarks and the legal system of judges and courts that help defend these rights.

More indirect efforts include:

- Protecting the integrity of the overall financial infrastructure;
- Bringing into being facilities for the conduct of early-stage and fundamental research;
- Fiscal policies such as taxation and the granting of credits;
- The educational system;
- Transportation and information infrastructures that make commerce possible;
- Government procurement;

- Assistance to trade through export financing;
- Protection against unfair trading practices by other countries, identification of trading opportunities, and efforts to open markets in other countries.

Government, though not a leader in setting agendas for the operations of the national innovation system, has had substantial effect operating through the mechanisms listed above. Changes in policy have led to noticeable changes in the system's operations, some improving the flow of innovative activity, and others acting as hindrances to this process.

In antitrust policy, adoption of a more tolerant enforcement posture in the face of the realities of international competition enhanced the ability of U.S. firms to increase their market power through domestic mergers and acquisitions. These changes resulted in several influential research consortia that are cited as a key reason for the resumption of U.S. competitiveness in several industries.

The Bayh-Dole Patent and Trademark Amendments Act of 1980 permitted small businesses and nonprofit institutions, including universities, to obtain intellectual property rights for developments based on research funded by federal agencies. This encouraged the introduction into the market of goods that might otherwise have remained "on the shelf." The Federal Technology Transfer Act of 1986 and amendments passed in 1989 authorized federal labs to enter into Cooperative Research and Development Agreements (CRADAs) with private firms, opening doors for technology transfer between government and industry and encouraging public-private partnerships.

In some areas of intellectual property protection, particularly patent protection, the U.S. has clearly been a leader in revising patent rules to adapt to the influx of new technologies. The international harmonization of patenting standards along the lines of the U.S. model acknowledges these strengths and has provided an opportunity for the U.S. to exercise leadership.

Perhaps of greater influence—a factor noted by industry leaders—is government's ability to help set an agenda for discussion, convene diverse interests, and

then act as catalyst for positive change. Government's role as a convenor of different interests helps to build bridges across disciplines and between upstream and downstream activities. One of the key features of the innovative process is network building. Through close interaction with competitors, suppliers, and customers, dynamic markets are created. To focus policy attention solely on the individual firm or even a single industry would be misleading. Relationships among institutions are becoming an important policy issue for government agencies. When such networks are weak, the government can play the role of broker between a firm and the other organizations that contribute to the innovative process.

Government is also able to mobilize capital in directions that are difficult or of little interest to industry. By focusing on areas that need particular help, or where basic research is not being conducted, government is able to leverage investment and create new knowledge that industry can use. Government is also a large and influential purchaser of goods and thus has influence on how products are developed, used, and marketed.

Finally, government also enforces rules that help to keep the system healthy. Moreover, government ameliorates macro-level problems that develop through private sector actions, such as environmental clean-up or consumer protection. While industry sometimes sees these types of actions as barriers to innovation, when viewed as part of the larger system within which innovation takes places, these rule-setting roles and efforts to ensure consumer safety are key to the overall facility with which innovation takes place.

Stresses of Public Sector Action – and Inaction

What, then, are those areas we might usefully focus on in asking what policy directions might be useful to address? Such areas of stress arise from two causes. Some obstacles—call them "inadvertent barriers"—like those emerging within the business sector, are a secondary effect of rapid change in the innovation system. Other obstacles—call them "purposeful barriers"—are policies designed to create or protect a public good or to help meet a public mission. This latter set of barriers are a part of

government action that clearly cannot be compromised, even if the result would be reducing barriers to innovation. The "stresses" on the system placed by purposeful barriers include tax policy, antitrust oversight, and export controls on products related to national security. Clearly, government must walk the fine line between aiding innovation while at the same time maintaining stability in a range of policies that affect economic and social order.

While purposeful barriers must constantly be reassessed to ensure they are still fulfilling their intended purpose, we are most concerned about "inadvertent barriers" where government can help by unblocking bottlenecks to innovation: This is doubly challenging because government is necessarily fragmented, with policies developed from different parts of a three-branch system, all of which directly affect the innovation system. It is hard to watch for signposts of change when so many players have an influence over the direction and character of government policy.

Nevertheless, several areas of federal government policy may be presenting inadvertent barriers. Section III is intended to address these with specific discussion of policy directions. For example, industry is increasingly expressing concern that the U.S. patent (and copyright) system is in fact creating a patent thicket, a dense web of overlapping intellectual property rights that a company must hack through in order to commercialize new technology. With cumulative innovation and multiple blocking patents, stronger patent rights can have the perverse effect of stifling, not encouraging, innovation.

Other areas where the government is challenged by the current complexity of the innovation system include how to allocate research funding across fields of science and technology. This challenge is proving particularly vexing, since most of recent funding increases for S&T have gone into health and medicine. Compelling problems in public health draws funds. However, there are places within the innovation system—manufacturing sciences and materials are two examples—where underfunding of S&T is harming U.S. capabilities. Addressing this imbalance is key to improving the system.

Beyond R&D spending, issues such as the R&D tax credit, export controls, and technical training for workers now and in the future are challenging the government to

come up with better and more responsive policies. The need from government for improved information management and dissemination is also becoming increasingly critical. Mechanisms to help government itself make better decisions can be improved. The government tends to be a hierarchical system in a networked world: instilling "change management" into the bureaucracy may be key to creating a government that is a partner in the innovation system rather than an obstacle.

The Innovation System in Times of Change

The dynamic innovation system depends upon fundamental conditions and rules of operation. Some of these conditions are planned and implemented by government policy, others by private sector action. Even with the best of planning, however, some features of the system are beyond the reaches of planning and policy. Innovative activity by its nature is a generator of surprises, but beyond this there are political, environmental, or social changes external to the innovation system which could affect it profoundly. Government and society in general may be unable to anticipate these adequately. Even in the most flexible system, certain challenges could stress that system to the breaking point. Over the next 20 years, the national innovation system will be subject to many stresses, any one or combination of which may upset the positive balances we have achieved.

To some extent, monitoring and adjustment is built into the U.S. innovation system. The Federal Reserve, for example, monitors the economy for potential shocks to the system and seeks to ensure stability in the money supply and the interest rate. The Department of Commerce monitors trade and other economic variables as a measure of the health of the system. The market itself is certainly the most powerful means we possess to interpret and react to change. It is a characteristic of an adaptive system to possess means to watch for change and generate actions to better serve, in this case, the health of the national innovation system.

Yet, it is entirely possible we may not care for the types of reactions that may be autonomously generated in response to change. Further, we may have choices or opportunities for shaping the directions of change in ways we might find more

comfortable. If we are interested in seeking policy directions that would be useful guides to actions in the future, it would be useful to see which actions appear to be robust against alternative futures. That is, what are those policies and stances we might wish to adopt no matter what future we face, and what are those that might help us better to face futures that represent strong currents pulling us off course? These questions provide a filter for sifting through possible policy directions for those actions most likely to serve – or be needed – across a set of alternative scenarios.

Overall, it is clear that government policy must build strengths and reduce weaknesses in a way that will ensure success under a number of conditions. Barring the ability to plan and manage with complete certainty, government must at least be able to mitigate shocks to the system and perhaps to watch for signposts of change that would indicate what shocks may be looming in the future. While change may come in any number of ways, for the purpose of discussion, disruptions in three broad areas are considered below: the social, political, and environmental.

Social Changes and Challenges to the Innovation System

Stresses and challenges to the system can include "good" things like greater citizen involvement in decisions about science and technology investment. One can easily imagine a future where a more technologically astute population exerts influence through normal political channels and through new, innovative partnerships to affect government decisions about trade positions, about patents, or about investment in certain technologies. Such efforts, similar to and downstream from the street-based demonstrations that surrounded the World Trade Organization meetings in 2000, could coordinate the interests of NGOs and other groups to affect directly government activities. This change in the governance of technology might come about or be precipitated by events that highlight the risks associated with technology--ethical, political and social--of what some might see as a "heedless rush into the technological future."

Although citizen participation in a democracy is a good thing, a more concentrated and organized populist approach to the governance of technology or the

levers of the economic system could result in greater social control over the pace and direction of innovation. These pressures could include demand for fiscal changes resulting from more politically active interest groups, increased protectionism as foreign interests are more easily sacrificed than domestic ones, political gridlock as the system strives for a sometimes unattainable consensus, and diminishing incentives for innovation and some capital/technology flight.

The constituency pressures which are a key aspect of this scenario may force an increase in spending and expectations of tax reductions which ultimately reduce growth. Increased demand for regulation could be another anticipated outcome. On the international front, increased trade friction could result from efforts to reach consensus among these complex sets of interests. Strengthening of the U.S. position relative to world organizations such as the World Trade Organization might be one rational response to changes suggested in this scenario.

Government innovation policy under such a future would be heavily influenced by public opinion, perhaps in a way that erects obstacles to innovation. In a case where public opinion about technology imposes greater costs on the system, the government would need to act more effectively in its role educating the public about the benefits of science and technology. Moreover, government would need to actively convene groups to discuss policies such as intellectual property, antitrust, trade, and other issues in order to strike a balance between maintaining a healthy innovation system that creates wealth overall, and the demands of individuals to meet specific goals of social justice or ethical outcomes.

Political Stresses and Challenges to the Innovation System

A second source of potentially different futures affecting the innovation system would be the return of international tensions leading the United States back into some of the postures of the Cold War. Regional power transformations might eventually draw the U.S. into direct or indirect military confrontation. Such scenarios would find the government challenged by ideological conflict, economic competition, misperceptions and miscommunication. The conflict could possibly renew emphasis on

military spending and R&D, and draw spending away from civilian R&D. While such tensions might catalyze increased support for basic sciences and engineering, the payoff within the innovation system would largely be focused on the military.

Although rapid innovation and diffusion might ensue in this "new Cold War" scenario, the winner would not necessarily be the national innovation system as a whole. In one telling of the tale, the benefits of innovation that have been enjoyed in the 1990s and early 2000s could evaporate. Emphasis on technology with military applications, for example in aerospace, systems integration, and so forth might create forces leading to lopsided economic growth. In another telling, however, the sources for technology development in the civilian sector have become so pronounced that considerable capability intended for the military might be derived from civilian sources.

In either case, the global diffusion of technology would most likely be somewhat less efficient as a consequence of efforts on the part of the U.S. to re-impose export controls on strategically sensitive technologies. Such controls could become extremely restrictive should the U.S. lose perspective and attempt to apply its laws to transfers of knowledge as well as to technologies, to all dual-use technologies, and to all technologies that have even an indirect effect military capabilities.

While the effect on innovation would be negative, in comparison to the previous alternate worldview where greater social involvement and democratization diffuses government power, this "new Cold-War" future would legitimize a heightened sense of authority for the state. The perception of a real threat to national security strengthens state power, enlarges the federal budget, reinforces government functions, empowers the official intelligence and military functions, increases the level of popular nationalism and patriotism, and expands the government role in inhibiting certain types of technology transfers. Thus, actions of government policy could be called upon to balance the effect on the innovation system of changes fomented by world conflict.

This could be a potential source of danger for the national innovation system and would require a conscious effort to walk a fine line. Government would have more control over and more of a need to maintain American leadership in key, leading-edge scientific and technological areas of national and international importance, and to make

sure that a sensible balance is maintained between civilian and military R&D, and between basic and applied research. The sense of urgency resulting from escalated conflict historically has been good for science and technology spending. The trick would be maintaining other government policies that transfer knowledge created into economic goods that continue to build wealth. This might mean a more active policy effort to identify important technologies, provide tax breaks for investment, aides to commercialization, and other positivist policies that are not now a part of government's chosen levers used to enhance the innovation system. But the sense of partnership and respect for the true source of innovative activity should not be impinged by a potentially more potent government authority.

Environmental Challenges to the Innovation System

A third source for potential alternative futures with respect to innovation policy might be a world where there is considerable breakdown of the social and economic structures imposed by catastrophic environmental change. This might come about because of an infectious disease pandemic, a severe energy crisis, an environmental/ecological disaster, or a combination of these events. This, like the others we have discussed so far, may not necessarily be a <u>likely</u> future in any true sense of the word, but the point is to examine the subsequent stresses this might give rise to. This type of thought experiment allows us to explore the adequacy of our system to retain some of its functionality under a number of different conditions.

In a future such as this, the downward spiral might be initiated by several external shocks to a vulnerable system, resulting in a radical shift in resources to ameliorate human suffering or economic damage. The result might produce low growth, protectionism, and the undermining of institutions being criticized for causing or not responding quickly enough to disaster. When projected on a global scale, environmental disaster could reduce the ability of wealthier countries to help poor countries. The conditions of the poor within rich countries would also deteriorate.

The sudden change in economic performance would lay bare a multitude of conflicts obscured by several decades of economic health. Within the United States,

significant social unrest could ensue. Ethnic tension might grow as unemployment among minorities increases. Resentment and violence against recent immigrants could rise, and rigid controls on immigration could be considered. Much of the regional economic cooperation that looked so promising at one time would also be retarded in this harsher economic climate. Globally, conflict might emerge: mercantilist conflict over markets, access to resources, and conflicts over access to food or medicine could erupt. In general, governments would be under siege, less likely to cooperate, and perhaps be more likely to find reasons to buy a measure of domestic tranquility at the expense of the interests of others.

Technological innovation is significantly impeded in this future world. Lower profitability, fewer economies of scale due largely to global protectionism and increasing regulation, and the general deterioration in the business environment reduce growth and investment. Significantly fewer incentives exist for investment in R&D. The entire innovation system would be weakened by lower profits, increased protectionism, immigration barriers that reduce availability of trained S&T workers, and increased regulation.

In a world such as this, where the national innovation system is in crisis, government would be in a position of trying to expand its role in stimulating innovation in order to jump-start the economy. Many of the levers of government policy would exist only in theory. However, the political environment would not encourage consensus on these policies and resources would be short. Government's most important role would be focused on maintaining social order and providing basic services; little attention could be given to encouraging innovation. Indeed, innovation and economic growth might be seen as the cause for some of the problems at hand and therefore, might be actively discouraged.

III. Policy Directions in Support of a Healthy National Innovation System

This chapter contains the heart of this document. It is a synthesis and presentation of policy directions that emerged over the past two years of NSTC-sponsored efforts to gather insight into the workings of the national innovation system and the intersection of that system's activities with public policy actions. As such, this section serves two purposes. The first of these is to lay out a unified structure of issue areas affecting the national innovation system. The second is to advance, in the form of general options, policy approaches for addressing specific needs raised in each of these areas.

In carrying out the first task of laying out the issue areas, we have designed a taxonomy oriented around process. We have chosen to avoid relying on systems of aggregation focused more on institutions, both public and private, in keeping with the view laid out in the first chapter of the national innovation system as dynamic, complex, and adaptive, needing to be addressed on its own terms. We wish to avoid dissecting the system in a way that loses sight of the dynamics that define it as a whole. The presentation is organized to emphasize support to U.S. innovative activity when viewed as occurring within an integrated system.

Presenting the issues in the way we have chosen also serves to emphasize that it is not the intent of this effort to lay out a narrow policy course to be followed by individual government agencies or other public policy institutions. Rather, in speaking of policy directions, based more on "verbs" than "nouns", the desire is to increase generality of the discussion of policy directions. Individual agencies or policy makers may then use these policy directions as a guide to crafting more specific actions or decisions. Therefore, the options are arranged to suggest means for

- **ensuring inputs** to the system,

- **maintaining** and, where needed, improving **the environment** for private and public innovative activity, –
- **supporting communications** between elements of the system, and finally,
- **better understanding the dynamics** which drive the national innovation system and creating appropriate policy in support of them.

The second task of this report is to lay out policy directions designed to address the issues outlined below. The report does so in the form of options, but these need to be interpreted as well. It will be clear to the reader that each issue area may be classified along several axes. The first is the degree to which there is a well-defined and well-recognized **federal responsibility** in the area. For example, the realm of education is an area of vital concern but one in which the federal role has traditionally been limited and responsibility falls heavily on state and local governments. This is not to say the federal role is not important,[16] but that there is a degree of shared effort under the U.S. system which requires explicit recognition. In the realm of policy over research and experimentation (R&E) tax credits, on the other hand, the federal role is preponderant. This shapes the way in which options in each of these areas are presented in the discussion to follow.

The second axis is more subjective. In some issue areas there are strong and discernible areas of **agreement on fundamental principles** or policy initiatives. Other areas are characterized more by divergent views. Again, by way of example, even though the federal role in education is relatively weak, the degree of unanimity expressed in the various forums permits fairly straightforward and forceful statements of policy direction. In the case of the R&E tax credit, however, the discussion has not yet reached a strong coalescing of opinion.

A third axis spanning the full range of policy options is **time horizon of action**. Some issues could profit from immediate attention while others would benefit from a more measured tempo for consideration. Finally, the options also vary, sometimes

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[16] There certainly has been a strong federal presence in areas such as school desegragation, and there has been a more recent push to introduce standards and assess academic achievement according to consistent norms.

within a single such issue, in **functional focus**. Some are suggestions for removing government policy obstacles that may exist within the system, others are explorations of possible new institutions or functions, while a third group call for greater understanding and research to properly inform both the need for policy and policies themselves.

Beyond the obvious problem in interpretation created by these multiple viewing axes, this also presents a practical problem in presentation. We have selected an approach to the discussion of each issue area intended to convey the degree to which apparent agreement was displayed at the various NSTC venues and elsewhere. Further, the degree of specific language used in presenting the various policy options has been chosen to also reflect the scale of consensus. Therefore, in the main the options have been tempered to reflect the area of agreement that does exist in as broad degree as possible. This approach emphasizes the first two axes of interpretation: federal responsibility and degree of consensus, at least as expressed during the Innovation Summit sessions.

To better highlight those options that deserve earlier consideration by any administration, we have used the time course axis of orientation to present a selection of such proposals. These are found in the concluding chapter of this document.

Ensuring Adequate Inputs

The national innovation system requires inputs to deliver the outputs associated with the different stages of its activity. This span of activity ranges from early stage knowledge production, through applied research and technology development, and on to commercialization and application of innovations in the work place. As one moves along this process, the fruits of individual efforts become more "appropriable," that is, those who fund and carry out the activities may be assured of capturing a sufficient share of the benefits to make the investment worthwhile. Earlier on, there is less assurance this effort may be channeled to private benefit. Much of the early-stage knowledge so created has the character of a public good, that is, a great deal of the

output from early stage efforts may diffuse widely and therefore be difficult to turn quickly into private benefit.

This public good characteristic, if left unaddressed, could create a serious problem of the commons: who is to pay for vital knowledge and other inputs to innovative activity when anyone may draw upon the fruits of the investment? This is the reason public policy has traditionally played a large role in ensuring the production of the inputs to the early knowledge creation process. The first options for public policy directions come out of this realm.

Education and Training

Options: a) Improve the quality of K-12 education in general and raise the level of math and science education in particular.

b) Expand options for access to science and technology education among groups currently under-represented in the workforce of those fields.

c) Increase opportunities for re-training in science and technology for the current work force.

d) Take measures to determine that resources and incentives are in place to ensure the output of a sufficient supply of technically-trained professionals from institutions of higher education.

Throughout the entire body of reports, conferences, workshops, papers, hearings, and interviews upon which this present document draws, one theme stands out from all others in the frequency of its exposition and the attention and prominence it has received: education. Education is seen, not surprisingly, as the key input to an increasingly knowledge-based economy and society. This is education writ large—from formal education, to training, to enhancing public understanding of the risks and benefits of science and technology. It is also seen as the critical element connecting the national innovation system, its institutions and practitioners to that larger society, its ultimate beneficiaries and constituency. If the input becomes a bottleneck, the system may not prove as bountiful. If the connection becomes strained, the constituency for

this activity may not be sufficient to guarantee that adequate provision is made to meet its needs. This would work to the general detriment of all.

Education also stands out from the larger discussion of policy issues concerning the national innovation system as being the one area where, contrary to a generally-positive view of the present state of progress, many have voiced concern over the current state of affairs. Industry leaders see this as one of the main potential sources of weakness that could undermine the new economic structure that has been put in place over the past decade. The issue, as is the case with many others in this realm of policy, boils down to concern over adequate preparation today for the needs of the future. There is a perception that the current state of education in too many sections of our country and society may seriously constrain our ability to maintain growth and productivity.

This concern for education was expressed in many ways. It may be reduced to three main issue areas:

Staffing the workforce in an economy based on increasingly sophisticated technology. Here, the perception may be stated quite simply although determining the reality and crafting solutions to address it may prove bafflingly complex. For years industry has spoken of an increasing disconnection between the sophistication required to operate the mechanisms of the technology-based industrial infrastructure we are capable of building and the skills that many in the workforce bring to the job market. The U.S. is seen as a giant standing on one foot of steel – the excellence of the system of university education – and one of clay: a system of K-12 education that leaves too many of its graduates seriously under-prepared in the skills required by a knowledge economy. Firms have been forced to undertake remedial programs to bring up the basic skill level of new hires before even beginning training in the specifics of operating particular technology.

On the other hand, this perception is often stated with lack of specificity and a reliance on anecdote – albeit anecdote of a forcefully compelling nature.[17] This problem area would benefit from a more quantitative approach to determining the shortcomings of U.S. K-12 education in light of the specific requirements of the national innovation system and the economy it supports. To what extent is this a problem of declining averages or of increasing variance? Are shortcomings relative or absolute: is skill-building in actual decline or is it failing to keep up with the increasing demand for skills? But at the end of the day, given the level of smoke generated by this concern there is a considerable national interest in determining where the fire actually lies and how it might best be fought.

This area of policy is an excellent illustration of an issue that not only connects a series of public and private interests but also spans all levels of governance, from federal agencies to the local school board. There is considerable room for coordination between levels to be coupled with local experimentation. What remains is the need for policy attention to be placed on K-12 education, and for all stake holders and responsible officials to consider the implications of its state of health for the future prospects of the national innovation system.

The rift between those who can manage successfully within a technologically sophisticated economy and society and those who cannot. Another question raised in the realm of skill-base building is the extent to which new or existing differences within the U.S. population may be exacerbated by differences in training and education. Again, the most recent statistical findings show a persistent gap in basic K-12 skill-building achievement between different ethnic groups.[18] The concern is that these gaps will become more exaggerated as opportunities for post-K-12 skill development and work experience introduce a reinforcing echo to differences already stemming from differential socio-economic levels and ethnic backgrounds. With attention and forethought this leverage could be made to work in the opposite direction. The

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[17] The most recent National Assessment of Educational Progress shows a declining rate of progress in math proficiency among 17 year olds compared with the gains of the 1980s and stagnation in the scores for science proficiency. (U.S. Department of Education, National Center for Education Statistics, "NAEP 1999 Trends in Academic Programs.")

[18] ibid.

premium likely to be placed on familiarity with and ability to operate within a complex technologically-based work setting may provide avenues for advancement and integration that perhaps would be more difficult to achieve within more traditional work and corporate structures. Which way this force operates, whether to further divide or to wash away barriers, will depend on choices made today and in the near future.

The differences in our society are not only the static ones of longstanding. The force of change brought about by the technologization of virtually every work place introduces an intense dynamic bifurcation as well. It has become a commonplace, but one worth repeating, that rapid changes in the technology of work and of health maintenance make it increasingly unlikely that the training received early in life will prove sufficient to serve an individual during the entire course of a work career. This could present our society with future challenges almost unprecedented in the course of human civilization. Previously, it has been the task of the older generation to pass along to the succeeding one the information and skills required to persevere and progress. But in a world being transformed daily by a revolution wrought by 20-year olds, where many of the basic elements of the work place, to say nothing of the very industrial structure of the nation, are subject to drastic change, this passing of the intra-generational torch is stood on its head.

The need for skill retraining at various stages of one's work life – and even in the leisure time of semi- or full retirement, is becoming clear. Individuals do, of course, manage to do this in many instances. Firms have focused a portion of their human resource efforts on internal programs of retraining and upskilling. Local institutions from vocational training centers through community colleges are turning to meet this emerging need. Yet, this is an issue that could profit from being brought more squarely into the forefront of policy consideration. It is unclear that the means for retraining current workers will prove adequate the task we may be confronting. There is also a clear component for public effort given the increasing mobility of workers and a sensible reluctance for firms to expend resources in teachings skills which may serve only their current employees' next employer.

The issue may also be seen to go beyond the fate of the individuals involved and may not just be a question of simple remediation for people marginalized by the march of progress. Rather, it may well be that the truly successful participants in the global economy of the future will be those nations who come to evaluate and design processes and technologies around a sophisticated understanding of how people learn, rather than to leave individuals and societies to play catch up with technologies. In this sense, the retraining issue, rather than being an appendage of education in general, goes to the very heart of understanding how humans learn and may operate in an environment where change comes not in episodes but in a continuous stream. This passes our present understanding.[19] The stakes for recognizing and meeting this challenge are potentially quite high and the possible rewards commensurate with those stakes.

When even the full dimensions of the challenge are not well understood, the specific policy actions to be followed are far from clear. This makes this an issue that might profit from the attention of several public institutions for whom concern for the national innovation system is part of their charge. Given the centrality of education and skill-building, this casts a wide net indeed.

Building, maintaining, and operating the national innovation system as the source of new technology. The statistics are troubling. The numbers of U.S. students gaining training in the advanced scientific and engineering skills needed to meet the demands arising from industry for technically trained professionals appear insufficient.[20] Already we have witnessed bottlenecks in certain professional areas, such as advanced software programming, that appear to be more than transitory. So far, the signals sent by the market do not appear to have affected appreciably the career selection decisions of entering college students. And even if this response began to be

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[19] At present, considerably less than 1 percent of outlays on education are spent on education research. ("Report to the President on the Use of Technology to Strengthen K-12 Education in the United States," March 1997. President's Council of Advisors on Science and Technology: Panel on Educational Technology.)

[20] As an example, a recent survey of mid- and large-size U.S. companies by the Information Technology Association of America showed 346,000 unfilled IT jobs in U.S. due to shortage of qualified workers.

observed, the flow through the pipeline for the foreseeable future has been largely already determined.

This is an area rife with questions of considerable complexity and subtlety that may only be cursorily alluded to in this presentation. They range from asking what signals are being sent and ought to be sent to potential science, math, and engineering graduates; to whether graduate education programs as currently designed are well-suited to meeting the actual needs of the larger society as opposed to achieving sufficient replenishment of the professoriate at advanced research universities; to what alternatives are presenting themselves to potential technical trainees and whether these are likely to be sustained; to what extent may special immigration status for technically trained professionals be used to address needs and what the long-term implications of such expedients might be; and finally, to what the long term implications for the health, operation, and motive force of the national innovation system might be if trends continue on their present course.

There is an interesting concomitant to this question. As we focus on the higher end technical skills required for innovation, we might well ask whether we are also making best use of innovative talent in the work force that may not at present be tapped to its fullest. The role of labor and its traditional division from the professional staff of a corporation may be changing. Continuous reskilling of workers make them valuable contributors to innovative activity, recognizing that much of this activity consists not of formal R&D but rather hands-on experimentation.

Time after time, when firms have attempted to inventory the knowledge they possess, they have discovered that only a fraction of this may be formally codified – much exists in the experience base of the work force. This realization is based on observation with a long tradition. Science exists in the head; technology comes at the touch of the fingers. Workplaces constructed so as to affirm the principle of change and use it to advantage will be intrinsically more productive than those designed to minimize the disruption inherent in change by directing it into familiar and traditional channels. Successfully doing so will require making certain all elements of the

productive value chain within a firm are engaged to the greatest extent possible in the challenge at hand.

The thread tying these policy directions and issues for consideration together, beside the obvious link of a focus on education, is the need for the various institutions, both public and private who each hold a portion of the responsibility and a stake in outcomes from this area to recognize the commonality of their interests. What is required is not a revolutionary centralization of direction and management but recognition of the need for concerted effort and enhanced flow of information. In what will be seen as a common theme running through much of what is to follow, the de facto partnership between business, educational institutions, and government should be made explicit. The multiplicity of interests needs to be utilized as a resource for confronting the daunting challenges ahead.

And finally, it is clear that the issues that have been raised are not necessarily a problem of supplying modern equipment or even of resources more generally. Rather they bespeak a need for gaining, on the one hand, a deeper understanding of how individuals learn and on the other how they can "learn how to learn" throughout their productive lives. This may well prove key to having the technologically-based society we are building reach the goals and aspirations we have set for it.

Portfolio of public research

Options: a) Ensure an element of stability and adequate levels of public funding for fundamental science and engineering research.

b) Funding decisions should be made in a more informed process for assessing priorities and providing balance across fields in a manner commensurate with the complexity of the national innovation system.

The second area of widest concurrence throughout the breadth of discussions upon which this paper is based was on the need for ensuring adequate public support to basic research. This view often manifested itself as a concern to avoid the mistake of thinking the private sector is willing, capable, or appropriate for taking over this role entirely.

Studies of the development and adoption by industry of innovations have demonstrated, on the one hand, the vital importance of fundamental scientific and engineering research as direct or ancillary inputs to the process, and on the other the long lead times often encountered before the findings from such research are put into application.[21] That this lag appears to be inevitably associated with the use of scientific findings is not too surprising. The relationship between basic science and technology development and application, though strong, is also quite complex. Fundamental research may just illuminate basic principle, but it could also point a clear path for technology development to follow. It may provide a fuller understanding leading to refinements in technology advances that have already occurred or may appear to be solely of academic interest – until years or decades later when such findings become crucial cornerstones for entire new technologies and industries.

From the policy perspective, this gap in time between the activities of basic research and those actively engaged in by operating industries may mask from the common view one of the crucial linkages tying together the national innovation system. A strictly linear model assuming only unidirectional flows—from fundamental scientific research leading to technology development which in turn yields new products and services—is a gross and often inaccurate simplification of the processes at work in the real world. In the complex adaptive system that is the national innovation system, basic research enters into many of the important flows and linkages in numerous ways.

The present dynamism of the U.S. economy is attributed to the actions and decisions of firms in established and emerging industries, and rightly so. But it is also true that many of the important technological assets forming the foundation of the new structure they have built were originally created through public investments in basic research made, in some cases, decades ago. Our present fortune stems from investments made at least as early as the 1960s. But given the accelerated pace of technological development and the recognition of its importance to the bottom line of firms, may we expect that this function will now be undertaken sufficiently by privately funded effort? The majority of observers of these processes and those directly involved,

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[21] See, for example, Edwin Mansfield, *Technological Change*, 1971. (New York: W.W. Norton & Co.)

either as providers of basic research or as the ultimate consumers in industry, agree that the need for public involvement remains.

The calls for public bodies to continue ensuring adequate funding of basic research activity are more than just special pleadings. By the very nature of private firms' goals and the fiduciary responsibilities of their managers to shareholders, companies most often need to pick and invest in early winners or lines of research that will lead to clear pay-off. This automatically biases their R&D toward the latter stages of the discovery process. Even if such private research were to be funded at dramatically higher levels than is currently the case, the resulting portfolio of activity would not be adequate to meet the public need.

That this is so is due to the multi-faceted character of the product basic research yields. Scientific papers reporting positive findings are only the most obvious output from basic research. It also yields human capital benefits in the form of training in scientific fundamentals, expertise and experience with particular fields, formation of networks among scientists and between scientists and technologists, and new experimental designs and protocols. Most important, it provides an increased number of "guesses" about nature which in turn lead to greater chances for serendipity to enter in as well as to an increased set of options for future action. And, of course, not all bets pay off: basic research is also an important source of negative results—explorations of areas of possible promise which are shown not to live up to their perceived potential. When all these outputs are considered, it becomes clear that a basic research agenda without a major component of public support will fail to provide the balanced portfolio the public interest—as well as the private interest—requires.

Even if we avoid having the present pace of technological change blinding us to this need for adequate public support to basic research for the future, we are still left with a need to confront the basic questions that are difficult to answer given our present state of knowledge:

- What constitutes "adequate" funding for basic research?
- How should priorities be defined across fields and with respect to our goals? What constitutes proper balance?

- What level of coordination is required among the many public research portfolios?
- How may we measure performance and return from this investment?
- How may we determine what is the appropriate occasion for public investment so as not to overstep those areas where private efforts may be relied upon?

These remain as the important public policy issues to be confronted. There is no central tendency to the discussion in part because these issues have only come to the fore in recent years. But public policy in this area faces no greater challenges nor greater need than to begin a concerted process of addressing them.

General Policy to Enhance Resources

Options: a) Consider whether making the R&E tax credit permanent would provide sufficient and necessary general incentive to the national innovation system and the larger economy.

b) Evaluate the effect of the R&E tax credit with a view toward determining where within the national innovation system there is most influence, what changes should be made to existing regulations and where other instruments might be required to achieve the desired effect.

Issues related to capital markets and the funding of elements of the national innovation system were the subject of considerable and wide-ranging discussion at the NSTC-sponsored venues. These issues are actively examined in the business press in every day's newspaper. Given the auspices for these meetings, there was a ample consideration of the public finance aspects of basic research initiatives as outlined above, but the private funding of innovative activity also received considerable attention. While a wide range of opinion was expressed, the general tenor was that the present intricate system for directing private sector resources to innovative activity works well. The mechanisms for private sector financing of innovative activity are rightly viewed as being highly developed and effective in the U.S., with telling results. To the extent that there were suggestions for specific policy directions that would

require more active measures by public institutions, two ideas, one general in effect and the other pointed toward more specific technology areas, gained substantial measures of interest and support for further attention.

Within the discussion of general approaches to providing incentives for innovative behavior by private firms, the specific measure receiving most attention was the research & experimentation tax credit. Enacted to date by Congress as a temporary measure renewed on a periodic basis, this policy is intended to boost spending on innovation and discovery. It gives corporations a 20 percent credit for qualified research and development expenditures *in excess of* a calculated base amount. The purpose, clearly, is to increase the funding of R&D by effectively lowering the internal "rate of return" hurdle corporations apply to proposed research projects before giving them the green light. Several bills have been introduced into Congress to make the R&E tax credit permanent, but none have passed to date. In addition, some changes to the present rules have been suggested. Among the most frequently heard proposals have been making more flexible the calculation of the base level for determining R&D expenditure qualification and reducing caps to make research-intensive start-ups more attractive.

The great attraction of the R&E tax credit is the generality of its application. It is untargeted in the sense that the measure applies widely across fields of innovation and sectors of industry. In the best estimate, it affects an activity viewed as generally beneficial through application of an indirect policy lever. Yet, all tax-based policies suffer from the problem that the instruments of taxation are not solely nor even primarily designed to steer activities in specific directions but rather are intended to provide funding for the government. All such initiatives, therefore, have implications, not often obvious, for both government funding and wealth distribution. Further, any rule-based policy operating through the tax code may affect firms and sectors differentially depending upon the way the rules are written. Small firms may profit less than large firms, newer firms less than older, and so forth. And perhaps the indirect approach, despite its inherent appeal, is less effective than we might wish, having insufficient effect in stimulating funding to sectors already less favored by private

finance while giving a welcome but perhaps less necessary windfall to investments that likely would have occurred anyway.

These remain as open questions, raised by those who either would like to see repeal of the law or modification of its rules. There is a widely-shared perception that if there is an area where private investment is not taking as prominent a role as it could and perhaps should, it is in long-term investment on earlier stage technologies. To what extent could this expedient address the perceived need? Given the possibly great positive effect on the resource balance within the national innovation system and the elegance of the fundamental approach of a R&E tax credit to stimulate innovative research, it would serve policy making bodies well to come to a better understanding of this measure's past, present, and possible future effect. The question of how best or whether to extend this lever should be among the issues addressed in the near term.

Targeted Policies to Enhance Resources

Option: Evaluate the development of mechanisms to encourage investment in emerging technology sectors that currently receive limited venture capital funding and how such sectors and points of advantageous entry might be determined.

As a general rule, consensus over public policy in the realm of innovative activity and in support of elements of the national innovation system tends to shrink as the proposals for policy become more targeted and narrowly focused on specific sectors, industries, or technologies. This was certainly the case at the NSTC-sponsored meetings. Even so, somewhat paradoxically perhaps, there was a general sense that some sectors of potential importance to innovative activity and national well-being are not receiving adequate attention from existing funding sources and that specific initiatives—or more properly speaking, general initiatives more narrowly targeted—might be beneficial from a long-run perspective.

The venture capital market which has become the source for the most significant investment in companies based on new technologies and innovations has a tendency to cluster around sectors with high profiles and correspondingly high short-run returns while avoiding investments in technologies that yield low initial returns but long-term

benefits to society. As an example, there is no shortage of funding available for ventures in information technology and biotechnology while this is not necessarily true in technological fields based on materials science. Sectors that have potential to improve social welfare, or even yield substantial returns over the long term are not necessarily attractive investments for the private sector in their earlier stages.

Even in the more favored industrial sectors, there is a public misperception, of some concern to discussants at the NSTC meetings, that private venture capital will satisfactorily fund the necessary early-stage technology development upon which the next wave of high-technology businesses will be based. This perception stands in opposition to that shared by participants, namely that today's venture funding, in general, builds upon a base of technological innovation already in hand.

There do already exist public programs that are general in character but are designed to achieve specific effect. The Small Business Innovative Research (SBIR) program, for example, is intended to reach out to small, early-stage firms who otherwise would have difficulty in raising capital for development of technologies taking their first steps toward commercialization. Government procurement practices have in the past and could with greater emphasis in the future be geared to affect the rate of innovation in particular directions identified as being of priority.

The devil, as always, is in the details:

- How are we to assess through public institutions where a present or future need lies and where such a nudge from policy initiatives might be required?
- What type of policy instruments should be applied? Suggestions have ranged from government guarantees of the type familiar in the housing finance market to create secondary markets for sharing risk-bearing to a new National Innovation and Technology Development Bank. Or are currently available means already adequate to the task?
- How are we to assess the net benefit we gain from employing such means?

For example, how are we to be certain that funding through some federal program will not only just serve to displace private funding initiatives that might otherwise have

been forthcoming?[22] Hence, a paradox: there is a wide view that such steps are a necessary part of the government's function in fostering the national innovation system, yet we do not really know how to carry this mission out with assurance of doing the right thing. This is an example of a general policy direction where considerable experimentation with program design is desirable and where a need for improved understanding exists.

Maintaining a Favorable Environment

Public policy has played many different roles in helping create inputs to the national innovation system. These efforts have run the span from direct knowledge creation in national laboratories to more indirect policies such as providing support for education or enacting tax credits for research and experimentation. In some of these areas, the funding of fundamental research for example, the government role is crucial. In addition to considering the inputs to the national innovation system we may also examine the institutional framework within which its activities occur.

Looking at the effort required to commercialize new ideas for products, processes, and services, for example, it is clear the principal players are in the private sector. Yet, providing much of the framework within which this activity occurs is an important function of government as well. This framework is defined by a series of legal, administrative, technical and other institutional structures that are either created or sustained by the actions of public authorities. Therefore, the second large category of public policy issues affecting the national innovation system examines policy directions intended to maintain and improve the structure within which private innovative activity may be pursued.

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[22] We should note that this question is the subject of active scholarship. Although not conclusive, recent studies suggest that government programs have an additive, rather than a substitution, effect. Two relevant papers on this subject are "The Government as Venture Capitalist: The Long-Run Effects of the SBIR Program," Josh Lerner (NBER Working Paper No. W5753) September 1996, and "Winning an Award from ATP: Pursuing R&D Strategies in the Public Interest and Benefiting from the Halo Effect," Maryann Feldman and Maryellen Kelley (NISTIR 6577), March 2001.

Intellectual Property Protection

Options: a) Consider what measures may be required to ensure that patent review processes maintain currency with new technology developments.

b) Assess the effects of recent policy changes (such as the Bayh-Dole and Stevenson-Wydler Acts) on the flows and balance of government-funded research and their effects on private sector activities.

In an economy where the national innovation system is a key player and knowledge is the chief currency of that system, the ability to define and defend intellectual property rights is crucial. This is an area fraught with complexities – technical, legal, economic, and political – and with international implications as well as domestic. This is an area where considerable divergence of sometimes passionately expressed views may be found as to the state and serviceability of the present system of patent examination and issuance, the quality of the patents being issued, the availability and cost of patent protection, and even over what ought or ought not be eligible for the protections the patent system affords. It is clear that there would be considerable benefit to the nation in coming to an understanding of what demands are being placed on the intellectual property protection system, how those demands have and are likely to shift, and how well the system is and is likely to be able to meet those demands.

Rather than dwelling on all that divides in this realm, it is possible to discern the main lines of policy initiatives appearing to receive some measure of general support. There is general agreement that the Patents and Trademark Office (PTO) within the Department of Commerce, as the fulcrum for government policy and action in the intellectual property realm, has heavy demands being placed upon it. Irrespective of other possible concerns with the system, issues arise from the sheer length of the patent review process. This lengthening stems from two related causes, both having implications for other issues, not the least being the quality of the patents that ultimately are issued.

On the substantive side, the sheer volume of technology that needs to be considered in determining novelty, utility, and non-obviousness -- the hallmarks for eligibility of protection -- for every application is enormous. What is more, we are

witnessing an increase in the phenomenon of innovation occurring at the seams between traditional classifications of technology. This places a large burden on individual examiners and the system itself to maintain currency in a wide range of fields to say nothing of the cross product between those fields. On the practical side, once able examiners do achieve a sufficient level of mastery to pass knowledgeable judgement they became extremely valuable potential employees for a private sector often feeling a labor pinch in precisely those areas likely to be the most stressing for the PTO and the patent protection system as well. Retention becomes an issue and runs a foot race with skill development and proficiency in the art of patent examination. These factors suggest a need for a comprehensive consideration of the twin problems of training and retention in the patent examination system.

Beyond this, there is a larger question of intellectual property ownership and the results of this ownership on the national innovation system. The Bayh-Dole Act decisively answered the question, "Who owns the results of federally funded research?" by vesting ownership in the performing institutions. In the U.S., this class of beneficiary is largely represented by the public and private research universities. The Act is held by many to have succeeded in putting academic research to work for the larger public good and is credited with promoting technology transfer of federally funded research findings. It is also clear that it is creating the opportunity for substantial wealth transfer as well. Others, however, have suggested that among the less desirable effects have been an undue focus by university administrations on revenue generation and intellectual property acquisition to the detriment of the freer flow of ideas and research findings within the research community as well as between researchers and private sector interests.

Various suggestions have been raised that Bayh-Dole should be changed in several respects, for example to make the researchers rather than their institutions the primary beneficiaries. These recommendations to modify with what is widely viewed, even by those counseling change, as an important government initiative stem from uncertainty over what the larger effects of Bayh-Dole and similar acts might be. In particular, this powerful tool is viewed as perhaps giving rise to the unintended consequence of transforming the role of universities as research entities. The concern

voiced by some is that the motive for gain and immediate payback through closer industry ties may undercut the universities' role as the principal creators of basic knowledge inputs.

Given the importance of university research in the national innovation system and the growing importance of that research for the science and technology base of industry, the nation would be well served by an examination of the present state of intellectual property rights in publicly funded research to determine what changes have occurred, provide some measure of assurance in a realm where uncertainty gives rise to unease, and assess the status and place of such research in the context of what the innovation system requires to sustain it.

Standards

Options: a) Begin a systematic review of the process for setting technical standards, considering both the potential importance and limitations of government involvement.

b) Consider the role and process of standard setting as an aspect of U.S. trade policy.

Setting technical standards is emerging as a key issue affecting not only rates and directions of technological development in many industries, but of basic research as well. Because of the somewhat indirect effect on innovation, the issue has been less likely to capture attention than others, but recently it has been brought more firmly into the spotlight by concrete example. Failure to agree on domestic standards for cellular telephony led to an alleged reversal of a usual source of U.S. advantage. This lapse has been pointed to as a principal reason why non-U.S. firms were able to capture both technological and market leads over their potential U.S. competitors.

Unique among industrialized countries, the U.S. standards infrastructure is a loosely coordinated system of federal, state and local governments, voluntary standards associations, trade and professional organizations, for-profit entities, and industry semi-permanent and ad-hoc groups. As the importance of technology grows in all industry sectors, the U.S. system will come to be more severely tested in its ability to be effective

in sustaining the domestic innovation system and economic growth as well as furthering U.S. interests and innovation in a global economy.

We confront not only a question of how and by whom standards are to be set, but also of when. Setting standards too late in a technology development cycle runs the risk that technical progress may be stymied by needless uncertainty as has been argued was the case in the domestic cellular telephony market. Yet, set them too early and promising lines of inquiry may be needlessly stifled.

Owing to these considerations, the sense in the U.S. has been that those closest to the development of new technology and to its practical adoption and utilization should be the ones who determine when standards are to be set and what form they are to take. The balance of views expressed during the NSTC-sponsored forums continue to weigh in on this end of the spectrum. Yet, there is also a sense that the government and public policy roles, supplementary though they may be, need to be recognized because of the unique challenges growing in this domain. This becomes clearer if we recognize that "standards" actually subsumes several concepts. The term may refer to technical specifications for emerging technologies but may also be used in the sense of standards being set by government at several levels (the example of construction codes is the clearest) for the types and performance of technologies within structures and systems.

Heretofore, the issue of standards in federal policy has tended to be treated as a technical tool intended to benefit industry, but not as an element of national trade strategy. This narrowness of focus becomes an expensive luxury in a world where trade and technical development crosses borders more easily than ever before. The government has a significant role to play in seeking to make certain that cross-national efforts at harmonization of standards does not come at the expense of U.S. interests. In particular, there is need to ensure that any standard achieving international status is subject to open and transparent procedures for standards development and is not used as a means for market closure. (For example, in many standards bodies, the United States has only one vote against the coordinated votes of the member states of the European Union.) Beyond this, the government should place itself on a standing to

assist and actively support private sector efforts to harmonize requirements among U.S. and non-U.S. conformity assessment and standards-setting bodies.

Having an effective presence in international standards negotiations will require making certain the domestic basis for international action is solid. The U.S. domestic system may work but at the price of being more vulnerable to duplication, overlap, coordination problems, and increased costs for its participants and users than might, in some circumstances, be offset by its benefits. Operating effectively overseas may mean better policy coordination among U.S. industry, government agencies, and voluntary standards bodies. This may be required to ensure effective engagement with the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC)—the world's de facto international standards organizations.

Does this imply a need for more directive role for government action in this area of policy? It need not and ought not: few would want to see a more leading role for public action on the substantive issues of standards setting. Yet, the government does have a potentially crucial indirect role as a convenor and provider of auspices for fostering discussion of standards Especially in the area of information technology, and with the obvious obstacle to U.S. entrance to the cellular market being readily apparent, members of the public will benefit if devices in one area of the country work in others. Indeed the establishment of a national market becomes dependent upon national standards for interoperability. To this end, the federal government could support needed national interoperability by working with industry's standards development organizations to fund needed technical analysis. But it could also provide an occasion for early discussion to take place among technology developers, potential technology adopters, firms in affected industries, and other stakeholders including representatives of consumer interests. In the absence of government involvement, it is difficult to overcome the barriers preventing such conversations to occur in a timely, and legally acceptable, manner.

At the other extreme are more established industries, like construction, where innovation diffusion is often slowed by lack of standardization. Federal, state, and local

governments might seek to utilize honest-broker non-profit institutions that can evaluate new materials and technologies for which no standards exist. Again, government can provide a venue or occasion for peer-reviewed processes in cooperation with stakeholders to pre-qualify and pre-approve products, thus obviating the need for the process to be repeated for every state or local approval agency.

Infrastructure

Options: a) Assess national needs for new measurement and testing systems that would create a benefit across industries.

b) Examine federal investment priorities to ensure public investments in infratechnologies are sufficient to sustain the growth and development of the national innovation system in desired directions.

The question of standards is just one aspect of the larger issue of ensuring the existence of an appropriate infrastructure for supporting the scale and direction of activity within the national innovation system. The term is a broad one. Even restricting it to a consideration of the technical means for carrying forward the activities of technology development, the infrastructure upon which the national innovation system relies may be seen to include not only the physical capital represented by research apparatus and laboratories but also "infratechnologies" that support R&D across a spectrum of technology sectors.

Science and technology analysts have identified three main categories of infratechnologies: (1) basic scientific and engineering data (such as specific data on chemicals used in engineering processes) needed to conduct R&D and control production, (2) measurement and test methods used in R&D, process monitoring and control, and performance verification; and (3) standard practices and techniques, such as process control models, that allow efficient design and use of industrial technologies. Typically, private companies under-invest in the development of improved infratechnologies, in part because they lack the needed capital and technical staff, and in part because of limitations inherent in being able to capture full private benefit from this type of effort as discussed in the first chapter.

This consideration suggests that government investments are justified when these types of technologies benefit large numbers of companies, or multiple technology sectors. Obviously, this is a realm where considerable specificity is required to determine what form of investment is needed and in pursuit of what ends. The point is not to enumerate what these needs might be but to make a case for making certain that the importance of this public function is borne in mind and not lost from view when priorities are set over federal expenditures in research by the agencies who manage portfolios touching these areas.

Partnerships

Options: a) Evaluate the importance of various kinds of partnerships, as well as public-private consortia, in pursuit of innovative activity, determine when the public good would best be served by their coming into being, and consider how they may be fostered.

b) Define clearly where the boundaries for legal cooperation and research lie among firms in the private sector as well as between firms and the government.

c) Consider what policy guidelines would be needed for informing the construction and operation of partnerships with a public component.

Given changing roles for financing, conducting, and utilizing the fruits of innovative activity, the general issue of partnerships, especially during the early stages of the innovative process, has come increasingly to be seen as an important consideration for the national innovation system. There exist many informal partnerships within the national innovation system, a principal one being that between the federal government and private industry in funding new knowledge. Formally specified partnerships come in many forms. They may be research collaborations between two firms, a firm and a public sector institution such as a laboratory or a university, or may be complex consortia consisting of many different types of participants.

The Partnership for a New Generation of Vehicles is one example of a multi-lateral partnership between government and industry, but there are others as well. The

NSF, for example, conducts a program for establishing interdisciplinary research centers in various fields of engineering and sciences on university campuses. Seed money comes from the federal government—with possible supplementary state and local matches as well—but much of the funding is provided through private contributions from corporations. This type of partnership clearly involves a wide assortment of players at all levels.

The phenomena of increased propensity or proclivity toward partnering may be seen as a result of several trends. As the importance of technology as a foundation for business grows and as the avenues for potential research multiply there is a desire to share costs, risks, and ensure participation in possible breakthroughs. The tendency is also a concomitant of the trend for corporations to externalize and contract for some research functions formerly conducted in-house. And this is also a reflection, once again, of the increasingly dense web of interactions that has come to characterize the national innovation system. Innovative activity is likely to involve some level of contact with up-stream suppliers and down-stream customers and potential users rather than being pursued solely in-house. The drive toward increasing the number and breadth of partnerships may come to characterize the national innovation system as it dynamically transforms.

Yet, "partnership" is a loaded word, freighted with past experience and often used loosely to cover a range of motives. The concern is that partnerships between and among firms may confer benefit beyond the stated purpose of reducing risks and R&D costs and increase the possibilities for informal, perhaps even unintended, collusion or other limits to competition -- perhaps not in the strictly-defined area of the formal collaboration but in other arenas and other markets. At the same time, consortia between public and private institutions could be seen as running the risk of potentially confusing their roles and changing the relationships between the partners to the possible detriment either of the public good or of those firms not included in such partnerships.

Nevertheless, although working from a small base of examples, the potential public benefit appears to be large while few instances of specific transgression have

appeared to date. Such efforts can lower development times while effectively lengthening the time horizons of firms who otherwise would need to consider only shorter term efforts. Certainly, both industry and universities have found collaborations to be quite fruitful in providing each party with benefits that would otherwise be foregone. So the question becomes one of balance:

- What are the dynamic effects of increased university-industrial, cross-firm, and public-private links and ties on several key components of the system for conducting basic research?
- What metrics may be used to assess the benefit stemming from such actions and how can this be balanced against potential harm?
- And most importantly, what is the role of such partnerships in public policy and what guidelines need to be considered when weighing such efforts?

This last point brings up an entirely practical consideration. In many instances, it is unclear where the legal boundaries for appropriate partnering lie. Perceiving a gray area, it has been suggested that firms will tend to shy away from what otherwise might be fruitful opportunities for partnership. This suggests a need for better information, perhaps through active steps by the Department of Justice, to clarify the limitsof these activities. From the government perspective, there may be more opportunities for collaborative partnerships among agencies or between agency programs and industry consortia than is realized. In many respects, it might be useful to consider creating a position of ombudsman to assist inter-agency coordination in pursuit of innovative activity.

Improving Communications

The national innovation system is a complex web of individuals, private organizations, and public bodies. The different participants in this system are networked in a dense pattern of formal and informal communications. To the extent that these communications flow easily, the system comes closer to achieving its full potential. The U.S. innovation system works so well in part because these necessary communications are generally well facilitated by the existing system. There are, however, areas where these communications may be improved. And it is possible to

imagine future circumstances that could be on us quickly where these communications become less easy. It is possible to examine this area explicitly to determine what policy stance might aid in supporting these necessary communications.

Coordination within the Public Sector

Options: a) Raise the awareness of federal agencies concerning issues affecting the national innovation system and their own roles within that system.

b Seek to define and identify best practice with respect to R&D priority setting, project selection, and technology transfer across federal agencies and promote learning and transfer of such practices to other settings.

c) Seek opportunities to create or use existing forums and venues to foster discussion among federal agencies, between federal agencies and their state and local counterparts, and between government, industry, and academia on issues of common interest affecting the national innovation system.

The federal R&D enterprise is governed by a larger set of policy actions made by government agencies that in turn either directly or indirectly affect the national innovation system. Although it is convenient to speak of a federal R&D portfolio, this is largely a de facto construct resulting from the aggregation of funding decisions made at agency and program levels. There is not in place a system that routinely marries these actions with higher level policy decisions so as to provide a means for active management of an integrated portfolio in the fullest sense of the phrase. In other words, revealed priorities largely emerge only after the fact from within that portion of the R&D system funded by the federal government. Only a portion of R&D spending is affected by goals set at the highest level; the majority of spending appears to result from the intersection of the political process with the mechanisms of agency and program level allocation.

That a more formally specified system is absent should not be too surprising if we take explicit note of just how remarkable this area of federal activity truly is. One is hard pressed to name other vital federal government functions in the discretionary part of the budget that cross so many Executive agency and Congressional committee lines

as does the federal research enterprise. It is hard to think of any parallel federal activity that has such importance and such a broad involvement of so many agencies. There are other specific programs with large scope spread about the federal structure (providing public assistance, income support, or transfer payments of various types,) but those are for the most part mandatory. Other vital government functions are contained in single agencies. And if this were not enough, the set of issues relating to the national innovation system needs not only to be monitored, administered, and acted upon across the government, it needs to be applied across quite disparate fields of scientific, technical, and market activities.

Interestingly, what we then find is that the parts of the public sector dealing with issues related to or arising from the activities and outputs of the national innovation system themselves constitute a complex network of systemic interactions neither easy to describe nor predictable in ultimate effect. To bring this point out even more starkly, public entities include not only federal agencies but offices and bureaus at the state and local levels as well. Ultimately, the question is whether the present system as it currently stands is sufficient to ensure that the public good will be directly served and will achieve the best allocation of resources toward meeting national goals.

A simplistic assumption would be that greater coordination is desirable and can be attained by setting high level goals and then proceeding to lower levels of decision making authority. Yet, the reality is that decision making in this area is embedded in existing institutions and political processes. Setting high-level goals and then rigorously enforcing them as the exclusive means for crafting priorities and making allocations on lower levels would, in effect, stand many aspects of the present system on their head.

Further, the simple hierarchical approach, if viewed in simplistic terms and taking as its model decision making processes utilized in other areas of federal activity, may not at all be well-suited for application in this arena. From viewed in light of evolving patterns in information flows and knowledge management, part of the

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[23] To give but one small example, basic research on fuel cells is funded by the Departments of Defense, Transportation, and Energy, as one might expect. But somewhat surprisingly, the National Institutes of Health also fund research in this area.

character of the national innovation system as a complex adaptive system stems from its the increasingly cross-disciplinary, cross-sectoral, and trans-national patterns of interaction and discovery. The development of these denser and more complicated knowledge networks has been supported by technology developments that in themselves have also powered a transformation away from hierarchical models of information flows and simpler lines of influence. To have an effect in this arena without a command and control apparatus that is neither being sought nor likely to be effective in the ways we would wish, there is need to take cognizance of these aspects of the fundamental architecture of the system we seek to understand and influence.

What is worth pondering is how we might be better able to achieve communication and purposeful articulation of observations, policies, and actions across the spectrum of public sector actors. Several possibilities suggest themselves, although the important point is that there is no clear mechanism presently in hand. Experimentation and planning are certainly required to achieve the desired effect.

Not all government agencies are equally well attuned to matters of science and technology policy despite the large effect their actions and activities, though peripheral to their intended purpose, may have in this realm. Recently, the older mainstay agencies such as the Departments of Justice and of State have determined that though they do not have primacy in these areas of policy, they would benefit from having in-house science advisors to provide the necessary insight and in-house expertise. Calls have been made for a technology ombudsperson to be appointed with a national innovation mandate. This office would be charged with determining how best to leverage federal R&D resources, serving as the natural venue for cross-agency discussion and coordination to occur, and helping facilitate the fostering of formal and informal public private partnerships.

There certainly is room for better cross-fertilization, diffusing best practices in dealing with S&T and innovation-related issues from agencies that have effective systems in place to those which might benefit from emulation. Especially in the realm of regulatory policy where newly introduced or prospective technology raises questions that might be difficult to deal with drawing upon the limited resources within a single

agency, there may be room for more regular and easier collaboration on information sharing, assessment techniques, and examination of consequences from several perspectives than is presently the case. Further, when considering such information flows and cross-agency learning, it must be remembered that Congress is one of the principal actors in framing federal policies and practices. Any attempts to widen channels of communication must also consider the vital messages sent between the branches of government.

And certainly, one of the principal characteristics of the national innovation system as a complex adaptive system is the propensity toward clustering, regional aggregation and the development of technology "hot spots." The most obvious example is Silicon Valley but several industries developing on the leading edge of particular technologies can point to similar phenomena. State and local governments have noted the potential for growth and for luring entire new industries in their nascent stages to parts of the country that have not previously been large participants in the industrial economy. Such efforts may or may not have sufficient foundation to pass beyond being merely considered a fond hope.

We may not know enough to enable us to reliably capture "lightning in a bottle" and create such technology clusters as a matter of deliberate policy. Nevertheless, it is likely that in the future governments at various levels will be examining aspects of the national innovation system with a view toward fostering developments in desirable technical, market, and geographic directions. This in itself suggest a need, at the very least, for cognizance of the various players in the public sphere and may provide a basis for considering coordinated or concerted actions that could meet the expectations of all actors – public as well as private – through synergies of actions that may well, in keeping with the inherent capacities of a complex adaptive system, lead to a whole greater than the sum of the individual efforts. Perhaps we might consider engaging in studies to understand what role government policy may actually play in generating or bringing into fuller maturity such potential hot spots.

Industry and Government

Option: a) Seek ways to recognize explicitly the de facto partnership and mutuality of interest between public and private sector institutions in support of the national innovation system and to enhance the complementarity of activities.

One salient point about the national innovation system brought out by the sessions at the NSTC-sponsored forums is that there are ever more points of tangency between the activities of the private sector in pursuit of business development and those of the public sector in carrying out its charges and responsibilities. These points of tangency have always held the potential for friction, for generating charges of petty interference with private efforts on one hand and callous disregard for public costs on the other. Yet, while such frictions do occur and the potential remains, what characterizes the present period in the development of the national innovation system is the extent to which there is explicit awareness and acknowledgement of a congruence of interest between public and private institutions. Both acknowledge the primacy of the other sector in certain spheres of responsibility and decision making; there is increasing agreement on the respective relative strengths that each uniquely possesses; both recognize that they will necessarily come to the same question with differing perspectives given their legitimately different goals and outlooks; and players in both the public and private sectors have made the strategic judgement that the answer to some of their particular problems lie in cooperation and complementarity with the other.

Section II above has provided a synoptic catalogue of what each sector provides to furthering the innovative activity of the U.S. and outlines areas where each contributes a capability that is lacking in the other. In what has followed in this Section III discussion, certain points of tangency and opportunity for mutually reinforcing actions have been elaborated in further detail. The purpose of the present option is to make explicit what appears to be both a fundamental change in shared outlook and a potential for a type of public/private interaction that has perhaps not before been possible. The possibility arises from the perceived needs of each potential partner to the transaction. It also stems from the increasing awareness that a technologically based

economy may operate according to a modified set of rules and a need for elucidating what some of those rules might be.

This is manifestly not a call for movement toward some structural merger of private and public interests and lines of responsibility. Quite the opposite: the only way a useful partnership in fact may be forged is through a clear recognition of the different spheres and modes for public and private action. To lose sight of this distinction and to seek a common voice for articulating issues would be to lose precisely the value of multi-lateralism and multiplicity of views that has been a main motive force for putting into place the necessary components of our emerging economy. Neither is this a call for either party to abrogate responsibility or lose sight of institutional interests. Rather, what is being suggested is that just as within the public sphere taken by itself there is considerable value to be gained by enhanced communication between agencies and levels of government, so too government agencies should seek means for framing and mounting initiatives with full consideration of the private sector as a source of insight and of implementation.

Consistent with preserving the role of agencies as guardians of the interests of the larger society, the networked character of the national innovation system should provide a basis for thinking through new means for early discussions, conducted under the convening authority of public agencies, to foster consideration of issues relating to the development of the national innovation system. Such conversations should include not only public officials and business managers, but also other relevant stakeholders. Emphasizing the early and preliminary character of such contacts will serve several purposes: reduce to some extent the anxiety to preserve perceived interests from possible threat, allow early elaboration of multiple potential means for action, and establish channels for the transmission of insights, experience, and knowledge. Most importantly, to do so would establish a means for carrying any commonly agreed action into implementation. The process for arriving at both a sense of the issue and the actions to be taken would become an important element in the mechanism for subsequent performance.

Clearly, this is only the broadest description of what perhaps should not even be termed a policy direction. Yet, it reflects a strong current for change that should be recognized and borne in mind when considering more specific measures. The goal is to identify those areas where the limited means available to those seeking action toward a common end may be made complementary and so hasten the realization of mutually satisfactory outcomes.

Improving Understanding by the General Public

Options: a) Raise public awareness of the importance for issues of general concern of innovative activity and what is required through public actions to support that activity.

b) Raise the prominence of formal awards for leadership in the field of technology development.

There is a view shared by many who concern themselves with science and technology policy that there has been an inadequate, or at any rate less than successful, effort in making clear to the general public the connection between many of the benefits they seek or have come to enjoy and the outputs from activities occurring within the national innovation system. In part, the various NSTC-sponsored meetings were intended as one step in the direction of improving somewhat this apparent lack of connection in the public perception. While individuals are surely aware of the many changes being brought about in their lives by advances in science and technology, it is less clear that there is a common awareness of the existence of a complexly intertwined national innovation system, one that requires inputs of adequate resources for operation and is not free from the need for observation and nurturing.

Surveys suggest that the public is not only less well-informed than might be wished about basic science and technology knowledge, but also rarely sophisticated in its view of the processes by which this knowledge is generated. Basic research findings are sometimes viewed as arcane or parochial or just plain silly. Worse, there is occasionally public consternation with ongoing research that either says too little or provides new facts which appear to contradict those reported in the newspapers of only

the month before. There is not a shared general awareness of the role such activities play in leading to more practical applications -- and often a sense that if such things are important to industry, then naturally private interests will ensure that such activities receive sufficient attention and access to resources.

There is danger here. Advocates of funding for basic research, S&T policy makers and analysts, and scientists and technologists themselves run the risk of, quite naturally, seeing the crucial importance of their own interests (in every sense of the word) and railing in a quite parochial fashion against the ignorance of those who either don't quite share their involvement or enthusiasm or perceive more pressing needs confronting our society. Yet, a case can be made for greater communication with the public on issues relating to the national innovation system on at least two counts.

What raises this area of public life beyond the narrow concern of those who are directly involved is its increasing salience for activities in so many areas of our social and economic life. It is precisely because its influence is broadening and its effects becoming more pervasive that it deserves a higher profile in the public consciousness. People are affected by innovative activity today in ways that shake to their foundations the most crucial tenets of individual lives such as privacy, means for earning a livelihood, health, education, environment, access to information, quality and effect of governance, as well as many of the intangibles contributing toward quality of life. The connection between the national security apparatus of the U.S. and the abilities to provide for our common defense and to project military power are clear. The connection – and even the existence – of the national innovation system as the wellspring of future growth and prosperity is less so.

The difficulty with making this connection in the public mind brings to light the second reason for trying to make efforts at increasing awareness. Quite simply, the connection <u>is</u> a subtle one. It is hard to follow the chain of causality between basic discoveries emerging from federally-funded basic research in science or engineering and the emergence five, ten, or even twenty years later of profoundly useful technological applications. The very existence of what we have called a national innovation system is in itself a proposition calling for more elaboration than, for

example, positing the existence of the U.S. armed forces. Add to this the many disparate elements, public, private, and mixed, constituting this system and the widely differing character of those elements – to say nothing of the network aspects tying them together – and the story to be told becomes far from simple.

But if it cannot easily be made simple, it may perhaps be made more accessible. This is not an area calling for bold initiatives as much as for small steps and, most especially, of becoming more attuned to possibilities that may present themselves. As but one example, consider the awards given by public and private organizations for achievement and excellence in technology leadership.[24] On the one hand, it is worth recalling that awards and prizes have been used until comparatively recently, in the broad sweep of technology's history, to provide a stimulus to innovation in desired fields. But for the present purpose, we should consider how such awards, both those existing and those in prospect, could be raised in prominence as a means for signaling to those who are not actively engaged within the national innovation system that there is something going on that touches them directly. This effort could be used, for example to increase awareness that some of the rewards to innovation in the public sector are lower costs, hence lower taxes, and a different quality of service. It could also serve to raise the profile of such activities as an occupation worthy of pursuing, one that has a great capacity not only for touching on our collective life but for providing recognition for those attaining exceptional achievement. Rather than have such awards be post facto means for relatively closed circles of interest to provide recognition to its members, consider ways in which they may become vehicles for conveying to those outside such circles what of importance is being provided to society at large and just why they should care. To do so would not only spread an educational message but would also serve to help make more clear that the national innovation system consists not of a separate class of individuals outside mainline pursuits, but rather has become an integral part of our social and economic fabric.

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[24] Some examples are the National Medal of Technology, the Discoverer Award, the National Inventor's Hall of Fame, the R&D100, the Ohio Governor's Award, the Draper Award, and the PACE Award, to name a few.

Maintaining the Dynamism of the Innovation System

The national innovation system may be characterized to some extent by naming the major players and sketching out simple diagrams of its structural elements. The flows and actions occurring between these elements are what is most difficult to capture. It is no secret that the innovation process in general is not well understood. This is not surprising for an activity driven at one and the same time by technical, economic, sociological, and political-legal processes. But beyond the complication engendered by so many bits and pieces, there is an underlying dynamic complexity that is the leading characteristic of this system and that has so far defied attempts at definition and adequate description.

There is a tendency to want to reduce the view of the national innovation system to a simpler model both for purposes of reductivist description and to create a more tractable platform for crafting policy. This is a temptation that needs to be resisted. The challenge is to learn to think in terms of the national innovation system as it actually is – a complex, largely self-organized system, constantly changing, as befits an area of human activity whose principal output is to provide a continuous force for change in the fabric of our daily lives. This is an area where the light tread is best, both in view of our limited formal understanding and hence great capacity for inflicting unintended damage, and in respect for what we do understand of the dynamic capacity for self-creation and modification that is characteristic of the innovation system.

Yet, here too, there are public policy considerations and needs to be addressed. We illustrate below some of these opportunities consistent with the astonishing realities of the national innovation system as it is and as it operates.

Toward Better Understanding of the National Innovation System

Options: a) Improve timely access to available government agency data on innovative activity; harmonize existing government data bases.

b) Increase incentives for agencies to collect data on innovation and technology use and transfer through special surveys and by expanding routine collections.

c) Develop new measures and data categories to improve understanding of the innovation system and the interplay between public and private actions.

This issue area is closely related to the need for supporting communications, but it goes deeper. We face three major sub-issues in this sphere:

1) Providing ourselves with better data on phenomena of importance to the development and health of the national innovation system;

2) Making good use of the data we do and will have available;

3) Improving access to these data.

Despite decades of study by economists and other researchers, our formal understanding of how the innovation system works and how it articulates with other economic and social systems is poor. This certainly has consequences for crafting government policies, either direct or indirect, in such a way as to have the most positive effect on this system. Further, this lack of understanding most emphatically introduces a new degree of uncertainty into business planning. This uncertainty will grow considerably more significant as the foundations of even the more traditional "smokestack" industries become increasingly dependent on a rapidly transforming technological base. Finally, it becomes difficult for the general public to perceive the importance of the national innovation system and science and technology in general when the connections cannot be clearly elucidated even by academics.

The case can be made, therefore, that the increasing importance of the nation's innovation system in our national life makes it incumbent upon us – the policy community, business, and the lay public – to gain a better understanding of its nature. Clearly, this is a large research agenda in itself and will require diverse groups of both theoreticians and practitioners, both public and private, to address themselves to a wide range of particular tasks. There is much important analytical and interpretive work to be done. But underpinning any effort to gain better understanding must be gathering and having access to data on the phenomena into which we seek to gain insight.

Considering, for the moment, only data on the contents of the federal R&D portfolio, we find that the information is maintained by the various funding agencies

and may vary in content from highly aggregated budget information to disaggregated project descriptions. There is considerable difficulty in finding common bases for combining "crosscutting" data collected by the different agencies. Moreover, activities not characterized as R&D but which are scientific in nature (i.e., weather data, space travel, mapping) are not included in descriptions of federal R&D activities, leading to some confusion during priority setting and coordination activities.25 Within agencies, there tend to be two distinct sources of data -- those containing budget and programmatic information generated for the annual budget justification process and those which track the disbursing of the agency's funds. The records in these latter systems are not uniform or consistent across agencies. In many cases these are not databases at all, but paper records. Generally, there are no direct connections between these two sources of data.

These are some of the problems with tracking federal activity affecting this policy arena. But to understand the status of the national innovation system, its needs and state of well-being, we would also like to have available other information on phenomena of interest. The Census Bureau's new Business Information Tracking System (BITS) represents a major advance, but an issue of coordination for the data already collected by the government still remains. For example, we still cannot adequately track new start-up businesses over time. Thus there is a value in having enhanced coordination in data gathering and maintenance. But beyond this, other data series would be of great value. Some examples would include:

- R&D spending collected at the business-unit level;
- Periodic innovation and technology adoption surveys in service as well as manufacturing industries; and
- Improved human resources data on training, career paths, and work patterns of technically trained people.

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25 The terms "R&D" and "S&T" are often used as synonyms. Not only do these terms carry different meanings in the defense and civilian agencies, S&T carries multiple meanings. Lack of awareness of this continually impedes efforts to improve planning, management, and coordination of federal science activities.

Responsibility for collecting and collating such data need not fall solely on individual agencies, both federal and local. Much could be gained by better harmonization among collected data sets linked to one another. Moreover, it might be possible to consider public-private partnerships to produce information useful to both corporate managers and public policy makers at less cost and effort and with less burden on respondents. The fundamental point of departure for the many alternative paths that could put us in better standing in respect to data is first of all to recognize both the need and the opportunity.

Anticipating Needs and Consequences:

Options: a) Explore new methods and means to assist in formulating policies that will be adaptive and robust to a variety of possible outcomes rather than static and restrictive.

b)Explore new methods and means to enhance foresight and forward thinking about developments in the national innovation system and the implications of its actions for the society and economy.

Having better, more complete, and more accessible data would surely be a tremendous boon to our understanding of the state of the national innovation system, its relation to the rest of our society and the economy, and the types of policy directions touching on innovative activity and its supporting institutions that would be most beneficial for the values we care about. But it is not sufficient. Many of the means and tools at our disposal for examining and analyzing these data do not perform well in the presence of the very uncertainty that is the most distinguishing characteristic of innovative activity. By their very nature, research, development, and innovation are probes into the unknown and will only come to fruition in some future we can only dimly outline at the present. Add to this problem of uncertainty that of complexity: the standard tools of analysis we have available to us are not well adapted to interpreting correctly the phenomena associated with and the probable outcomes ensuing from complex adaptive systems such as the national innovation system.

This situation creates two related gaps that we should seek to fill. The first of these would be to improve our instrumentation to better anticipate both emerging needs and possible outcomes. Can we craft tools to give us a better view "over the hill?" The second gap must address our desire to find means for crafting policy in a way that leaves us less vulnerable to our limited means for perception and provides for more adaptive and flexible response to emerging events and future outcomes.

The first of these gaps is the more widely recognized of the two. Industrial nations around the world, as well as private corporations and industry groups, engage in efforts at what is most often termed "foresight". The National Critical Technologies Report process in the U.S. was, in part, imbued with this spirit. By way of an example of the type of need we might wish to better understand, one area of technological activity has stood out from the rest in recent years by virtue of the concern sometimes expressed for U.S. accomplishments and capabilities. In most National Critical Technologies Reports, including the most recent, there have been calls for more attention to the domestic development and adoption of manufacturing technologies. The concern has been that outside of the automobile industry and microelectronics manufacturing and its associated sectors, the U.S. stands as less of a giant in advanced machine building than in other areas of technological achievement. But even if these observations could be supported at more than the anecdotal level, they require further elucidation to determine their meaning for policy. Leaving aside for the moment the question of how much the data would support this contention about U.S. machine building, what would such data mean? In a complex adaptive systems view of innovation, would such an observation be a cause for concern or merely a phenomenon to be noted? If true, what alternative outcomes for the future of the national innovation system and the nation's health does this portend? Our current means for engaging in such conjecture are limited and ineffective.

An example of a clear desire to gain foresight into potential outcomes is provided by the recent National Nanotechnology Initiative. The review of the Initiative by the President's Council of Advisors on Science and Technology also recommended that a fraction of the total funds expended by the federal government be set aside for research into the socioeconomic consequences of developments in nanotechnology.

Such research will largely be probing unknown territory. It is by no means clear we have the tools and means to make such assessments *ex ante*. No doubt the crafters of the Initiative would not expect the fruits of such inquiries to be either definitive or conclusive. But to cite explicitly the importance of the effort is to emphasize the utility of making this type of question and endeavor more common. We will get better at gaining this insight and catching glimmers of the future but only through practice, trial and the inevitable error.

The second of the two gaps is more subtle than the first, but speaks at some level to the common sense we all possess as individuals. Related to the quest for foresight or more sophisticated understanding of alternative outcomes and future states of the world in terms of technology directions, is a desire for tools better adapted to addressing questions arising from the national innovation system in its character as a complex adaptive system. Though rarely expressed explicitly in the course of the various NSTC-sponsored meetings and other activities upon which this paper draws, there was nevertheless a common thread running not far below the surface of many of the discussions that did take place. The connecting theme is a frustration with the subtlety of the policy tasks we face and the limited means for crafting policy in a way that will meet the test.

Currently, the means to determine options and craft policies in a complex arena almost universally demand single-point predictions and then proceed to develop some optimal, "best-guess" strategy or policy.[26] As a corollary, in most cases there is an implicit assumption that there is a unitary decisionmaker (rather than a resolution among a wider set of legitimate stake-holder interests) taking a once-and-for-all policy stance (rather than adopting a strategy of adaptation) that will stay the course from today until the period being considered (irrespective of the fact that we will know more tomorrow than we do today.) These are not characteristics of either our present political system or our national innovation system. The effect is to constrain policy choices, disenfranchise certain categories of knowledge and other information inputs that do not

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[26] What will be the budget surplus/deficit in FY2017? The solvency of Social Security and Medicare? What will be the extent of global warming in 2025? What effect will this have on the global economy?

fit easily into our analyses, and lead to confrontational debates centered on arguments over which currently unknowable fact is most likely to prove true. Of course, in the real world adaptation naturally occurs as more and better information becomes available. But this is rarely hard-wired into the policy from the onset.

What, then, is needed? Certainly there is need for exploration. But for this exploration to occur and be encouraged there must first be explicit recognition of the need. Current attempts at foresight generally involve convening or just polling expert groups and sometimes involve exercises in building alternative narrative scenarios. Are there other alternatives we can try by widening the discussion beyond the traditional bounds via use, for example, of web-based tools? Are there means made available to us by our sudden, astonishing richness in computational resources that would free us from needing to settle on a single most likely future and that would instead permit a more realistic, sophisticated, and open understanding of the multiplicity of possibilities to be considered – without overwhelming us? And finally, is it possible to gain a new conception of the policy formulation process that will allow us to build in the flexibility and adaptation to new information that we all as individuals use almost unconsciously as the way to confront inherently uncertain choices?

Making strides in these directions would, in itself, be an innovative activity, providing better instrumentation for observing phenomena about which we care a great deal in very much the same way that the latest large astronomical arrays, for example, permit observations of physical phenomena that our own native senses would leave unperceived.

Measuring Performance in R&D

Option: a) Work to improve methods for measuring the long-term social and economic performance of investments in basic research.

In private industry, research portfolios are managed in such a way as to meet the needs and aspirations of the parent company. Across firms this might lead to varying emphases and assortment between stage of research (basic research, applied research, development, testing and measurement, etc.) and research planning time horizon

(results are expected in 2 months, 6 months, 3 years, etc.) The construction of the actual portfolio will depend upon the technical needs of the firm, resources available, the industrial sector, corporate culture, and perception by corporate managers of their fiduciary responsibilities toward shareholders. This may lead to wide variation in research style and allocation and effort, but generally speaking there is usually in place some system for tracking performance and keeping score.

The measurement problem is made easier in industry because the research they conduct is designed to be purposeful from the onset and usually is targeted towards a short time horizon and a practical application foreseen in advance. At the same time, it is generally acknowledged that much of the research conducted in the private sector is based upon findings generated by fundamental research either produced by or funded by the public sector. The output of the nation's research universities, for example, is pointed to by U.S. firms as a tremendous source of strategic advantage. Yet, unlike the private sector research, the basic research usually sponsored by public institutions may be very difficult to trace directly to measurable outcomes.

This raises a serious question for measuring performance in this area of public interest: how do we determine what priorities should be in research and measure the achievements of the programs we put in place to meet those research priorities? Policy is predicated upon a belief, backed by examples, that public investments in basic research have had a considerably positive effect on social welfare over the long term but were not attractive investments for the private sector until considerable spade work had already been done. Yet, we are not well placed to fully measure those benefits because of the passage of time and the complexity of the network required to lead to a final, measurable result.

This issue of measurement may be seen as a third aspect – along with the data and analysis issues and methodological concerns outlined above – to be addressed if we seek to improve our tools for understanding the issues faced (and posed) by the national innovation system and so stand in better stead to craft appropriate, targeted, and efficacious policy responses and initiatives when and where needed – as well as to recognize when and where they are not required. It is notoriously difficult.

Although methods exist to measure the performance and quantify the benefits by looking at research assets created or focussing on the formal documented output of the research process, our real interest is less in measuring formal output than in measuring actual outcomes in values we care about as a result of research. Here we may employ narrative retrospective analyses or applications of economic techniques and concepts. Advances have been made in the latter, but there are still large conceptual and methodological issues to overcome, especially when applied to federally-sponsored or –funded research. To name but a few issues,

- Much federally funded research is directed to areas where there is only a limited market at best, hence measurement of benefit is difficult to assess.
- Given the types of data available, the returns that result from most calculations of performance or benefit must be interpreted as average rather than marginal rates. From the policy perspective, this aggregate analysis means we cannot be certain of what implications to draw for the effect of an additional dollar of expenditure on research.
- A strict cost/benefit framework may itself be too restrictive, failing to capture the many types of benefit which may be derived from publicly-funded basic research. The true effect of such outlays may well be indirect, affecting productivity through changing the returns to private research and development rather than directly as a result of the specific research project.
- And the public basic research portfolio is huge: Basic research is conducted in a wide range of fields. The mechanisms for integrating research findings with practical development work may differ considerably from field to field.

Developing methods is only one side of the coin. Any method, no matter how clever, yields little benefit if not used. Here, even the limited progress made in evaluation and assessment has tended not to be implemented by the research sponsoring community.[27]

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[27] See, Ronald N. Kostoff, "Handbook of Research Impact Assessment, 7th Edition", DTIC Report No. ADA296021, Summer 1997; p. 4.

Recent changes in measuring government performance, such as the Government Performance and Results Act (GPRA) have resulted in a larger interest in and constituency for implementing performance measures. Agencies whose missions are congruent with much of the activity in the national innovation system (e.g., National Science Foundation, National Institute for Standards and Technology, National Institutes of Health) have devoted considerable resources toward the problem of applying GPRA to this area of government activity and have produced some major advances in meeting the need. In spite of these heroic efforts, few would argue that this does not still remains as an important direction for policy in regards to the national innovation system.

International Dimensions

Options: a) Identify centers of excellence in science and technology to encourage linkages and leverage across national boundaries;

b) Examine the global patenting system for ways to improve process efficiencies;

c) Identify ways that government can facilitate product and process standardization across national boundaries and determine when it might be appropriate to do so from the perspective of U.S. interests.

The dense web of activity and interaction that has come to characterize the national innovation system does not end at the nation's borders. The flow of knowledge across national boundaries is a key feature of innovation and growth. Collaboration at the research and development stage is an increasingly important factor in the discovery, application, and diffusion of knowledge: patenting and publication data show that R&D increasingly takes place across or regardless of national boundaries. Companies seek sources of innovation wherever they exist.

The problem of adjudicating among competing priorities for scientific and technological investment—always a complex problem—are made even more complex as the nature of new knowledge creation becomes collectivized and the locations at which these activities take place disperse globally. Yet, this can also be an opportunity. Growth over the past 20 years in S&T investment and infrastructure world-wide has

resulted in more distributed conduct and broader excellence in science around the globe. Even relying on nation-states as a grouping for scientific activity does not represent the whole picture. Often, a world-class capability exists in what would otherwise be called a "developing" country.

In many areas of science, no one nation can make the investments needed to stay at the head of the pack: the economies of scale require cooperation. Desire to share risk as well as participate in potential gains is also a strong force. Moreover, it does not make sense for each country to invest in duplicative infrastructure for key areas of science. Collaboration can create efficiencies. However, businesses and university-based researchers need to know where to look for excellent research, resources, and know-how. Creating a database of information about where excellent research is taking place in key fields of science and technology would certainly facilitate this kind of leveraging of the world's knowledge resources.

The global patenting system represents a large stock of knowledge about current processes and products that make up the innovation system. Yet, different national approaches to protecting intellectual property act as a drag on the system. The lack of channels to adjudicate problems or examine challenges raised by new technologies creates a gap that obstructs progress. While it is clearly the case that international treaties and protocols of a complex and delicate nature govern international intellectual property, it is not so fragile a system that it could not benefit from study as to how to make it more efficient and effective. A series of conferences on intellectual property and technology may help to focus U.S. government interests and perhaps suggest future action.

Likewise, international standards represent a kind of intellectual value and facility for commerce that is critical to high technology industries. The system of voluntary standards-setting works well in many sectors. But, there are certainly areas where U.S. interests are not well served by the current system. There may be, in select areas, a need for greater government action and intervention in the standards-setting and testing system in order to grease the skids of innovation and help U.S. companies. This may entail, and perhaps would primarily entail, government exercising its power

to convene different interest groups to come together to form a consensual, problem-solving approach to setting standards. It may also entail governmental representatives taking a more active role in standards-setting bodies. This is not to suggest changing the mission of government in this area, simply to encourage greater activism for government in the role it already plays. Private sector leadership would still be needed, along with a more active partnering with universities and other stakeholders in the standards process.

IV. Options for Near-Term Attention

Given the complex and interactive nature of the national innovation system, no single policy action will serve as a sole means for enhancement. Like a finely-tuned motor, all the features of the system must work well and interact effectively. However, in the course of preparing the policy directions outlined above, the project team came to believe that they were not all necessarily of equivalent weight and immediacy. Some could be identified as actions to be undertaken at the federal level in a relatively short time that might improve the overall operation of the system. These are offered below as candidate early agenda items for careful consideration by any federal administration seeking to support innovation. These options fall into three categories: 1) those reflecting a change in federal government policy and needing budgetary action; 2) those requiring legislative action; and 3) those needing near-term and effective examination and study.

Budgetary Action

Among the policy options listed in the previous section, perhaps the most important is **ensuring an element of stability and adequate levels of public funding for fundamental science and engineering**. Money should not simply be thrown at the R&D system in the expectation that useful outputs will ensue. Yet, there is every indication that the traditional valuable role played by federally funded basic research has not diminished and might well be increasing. Recent increases in private sector recognition of opportunities for R&D investment should not be confused with the type of activity that is unlikely to be pursued except through publicly provided means. Bipartisan support in Congress for increasing federal spending on R&D has grown over the past three years, with several promising proposals before the Congress. But spending should not be targeted solely to one or two "hot" areas. For example, recent statements by scientists, including those of the National Academy of Sciences, have questioned the wisdom of rapidly increasing the budget for the National Institutes of Health (within the Department of Health and Human Services) while other important areas remain flat or decrease in funding. Studies show that is it not possible to anticipate where exciting new developments will arise. Increased funding across a carefully constructed "portfolio" of investments will help ensure the health of the national innovation system.

Legislative Action

- In parallel to options for publicly funded R&D, an item that should command early attention is to **carefully consider the benefits and implications of making permanent the R&E tax credit**. This tax credit has been available on a renewed temporary basis for a number of years and has wide support among business leaders as an incentive for innovation. It could be made more effective as a permanent tax credit, thereby aiding planning for future R&D spending. But there are also those who question its necessity and efficacy. In view of increased support in Congress to enact a permanent tax credit, the issue calls for careful and comprehensive early examination.
- Similarly, some of the most significant public S&T policy acts by Congress in the past two decades have been directed towards making certain that current arrangements for assigning intellectual property from publicly funded research efforts fully serve the public purpose. In this light, it is time for Congress to **assess the effects of these policies (such as the Bayh-Dole and Stevenson-Wydler Acts) on the flows and balance of government-funded research and their effects on private sector activities**. While the conventional wisdom holds that these measures have added considerable vigor to innovative activity in the U.S., it would serve the nation well to ascertain that deleterious albeit unintended consequences have not also accompanied these changes. It may well be that some tuning may be required to permit the legislative intent to meet fully the purposes these acts were meant to serve.

Preparatory Action

- Clearly, information flows within the national innovation system are a primary cause for its dynamism. Information engenders new opportunities for innovation and the new ideas, in turn, require protection. Intellectual property protection is an element of support to the national innovation system specifically provided for in the U.S. Constitution. How information flows, who controls and owns it, and the effectiveness of adjudication measures directly affect the health of the system. In the crucial realm of intellectual property rights and their protection, a new administration should carefully consider the global patenting system and the effects of varying protocols and regulations on the ability of the U.S. to promote its products in world markets. Similarly, an improved understanding of the flow and

balance of government–funded research and the effect of technology transfer on the private sector is crucial for a clearer policy perspective on the overall system. A general review of policies in the areas of intellectual policy formation, transfer, and protection would be in order.

- Trained workers make the economy go. The U.S. technology-based industries report that critical shortages of trained personnel are hampering the rate of innovation. Increased attention should be paid to opportunities for training and re-training the science and technology workforce.
- Finally, although broad in concept, raising awareness within federal agencies of their role in providing the infrastructure for the national innovation system could play an important role in the consideration of policy, improving its formulation, and in better serving the public interest. Within this general mandate, several initiatives could be considered ranging from raising the prominence of formal awards, such as the Malcom Baldrige Award, for excellence in areas of technology development or quality assurance, to exploring means for rapidly identifying and diffusing among agencies best practices in dealing with the complex issues of national innovation system support. The rapid transformation being brought in the business and social spheres through changes in S&T should be reflected by a federal mechanism that is responsive to changing needs and requirements.

Appendix: Notes on sources

The discussion in this report drew upon several sources in attempting to craft a main line position on issues affecting the national innovation system. The principal sources were various reports and activities sponsored by the National Science and Technology Council (NSTC) and overseen by the Office of Science and Technology Policy (OSTP). However, thematically related material produced by the President's Council of Advisors on Science and Technology as well as reports and deliberations by non-governmental organizations were also consulted in reference during the production of this report. These included the following:

1. New Forces at Work: Industry Views Critical Technologies[28]

The Office of Science and Technology Policy in the Executive Office of the President asked a RAND Science and Technology Policy Institute research team to engage business and industry leaders explicitly in a discussion of the issue of critical technologies by gathering private-sector views on what technologies are appropriate to consider under this rubric--and why. This report presents an analysis of the information gained during the course of interviews with senior executives of several firms. The report was issued by RAND with the intent by OSTP that it be considered as the fourth and final in the series of National Critical Technologies Reviews.

2. NSTC Innovation Summit Policy Formulation Sessions

The National Science & Technology Council's Summit on Innovation, "Federal Policy for the New Millennium", was held November 30 and December 1, 1999 at George Washington University. As part of the process, nearly fifty short papers were contributed in response to a request from Dr. Neal Lane, the Special Assistant to the President for Science and Technology, for recommendations of potential federal actions to support innovation. The summit included several hundred attendees from

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[28] Popper, Steven, W., Caroline S. Wagner, and Eric V. Larson, New Forces at Work: Industry Views Critical Technologies, Santa Monica, Calif.: RAND, MR-1008-OSTP, 1998.

universities, government, labor, and private industry. Two days of formulation and discussion sessions were convened to focus on issues culled from the papers. The themes for discussion at the breakout sessions were:

- Awards and Leadership Groups as an Incentive to Innovate;
- Capital Markets: Barriers and Opportunities for Innovation;
- Government, Data, and Innovation;
- Harmonization of Policies Across Spheres of Governance;
- Intellectual Property and the National Innovation System;
- Partnerships, Anti-trust and Fostering Competition;
- Peer Review, Priorities, and Performance in R&D;
- Procurement Obstacles to Technology Innovation;
- Public-Private Partnerships in Standards Development;
- Priority Setting in Support of Research and Development;
- Talent Pool for Innovation;
- Trade Policy Agenda for Innovation; and
- Using the Internet to Foster Innovation.

Each group presented the results of its sessions at the Summit's final plenary meeting. The slides from the presentations may be viewed at the following site:

http://www.rand.org/centers/stpi/summit/index.html

3. Innovation summit papers

On August 5, 1999, Dr. Neal Lane requested that the NSTC's Committee on Technology (CT) identify priorities for reforming Federal policy to enhance innovation. The CT solicited input from industry, academia, non-profits, and state, local and Federal government on opportunities for Federal policy and regulatory reforms that will enhance the U.S. national innovation system. The CT invited submissions in the form of

"issues papers" to identify top priorities and outline ideas for reforming Federal support of innovation in four areas:

- Federal policy and/or regulation that have impacts on the ability of capital markets to serve as sufficient drivers of innovation, including both those which address market failures and those which hinder or limit market incentives for innovation;
- Federal policy and/or regulation that fosters basic and applied research by any participant in the national innovation system;
- Federal policy and/or regulation that fosters opportunities arising from crossing technology streams to stimulate innovative products and services; and
- Federal policy and/or regulation that have impacts on state, local, and international innovation policy, including opportunities to promote greater harmonization and coordination.

Several of the issue papers submitted may be viewed at the following site:

http://www.ostp.gov/html/rand/summit/IndexPage.html

A draft overview of the papers submitted in response to Dr. Lane's invitation is also available online at:

http://www.rand.org/publications/DRU/DRU2237/

4. NSTC Committee on Technology Innovation Scenarios Workshop

The National Science & Technology Council, Committee on Technology, held an Innovation Scenarios Workshop on June 21-22, 2000. On the first day, alternative future scenarios were developed by approximately twenty-five invited participants to describe distinctive plausible ways in which the innovation system might evolve over the next ten to fifteen years. On the second day, the findings from the Summit on Innovation: Federal Policy for the New Millennium held in 1999 were used and extrapolated with the findings from the scenario process on the first day, in order to determine policy implications and options.